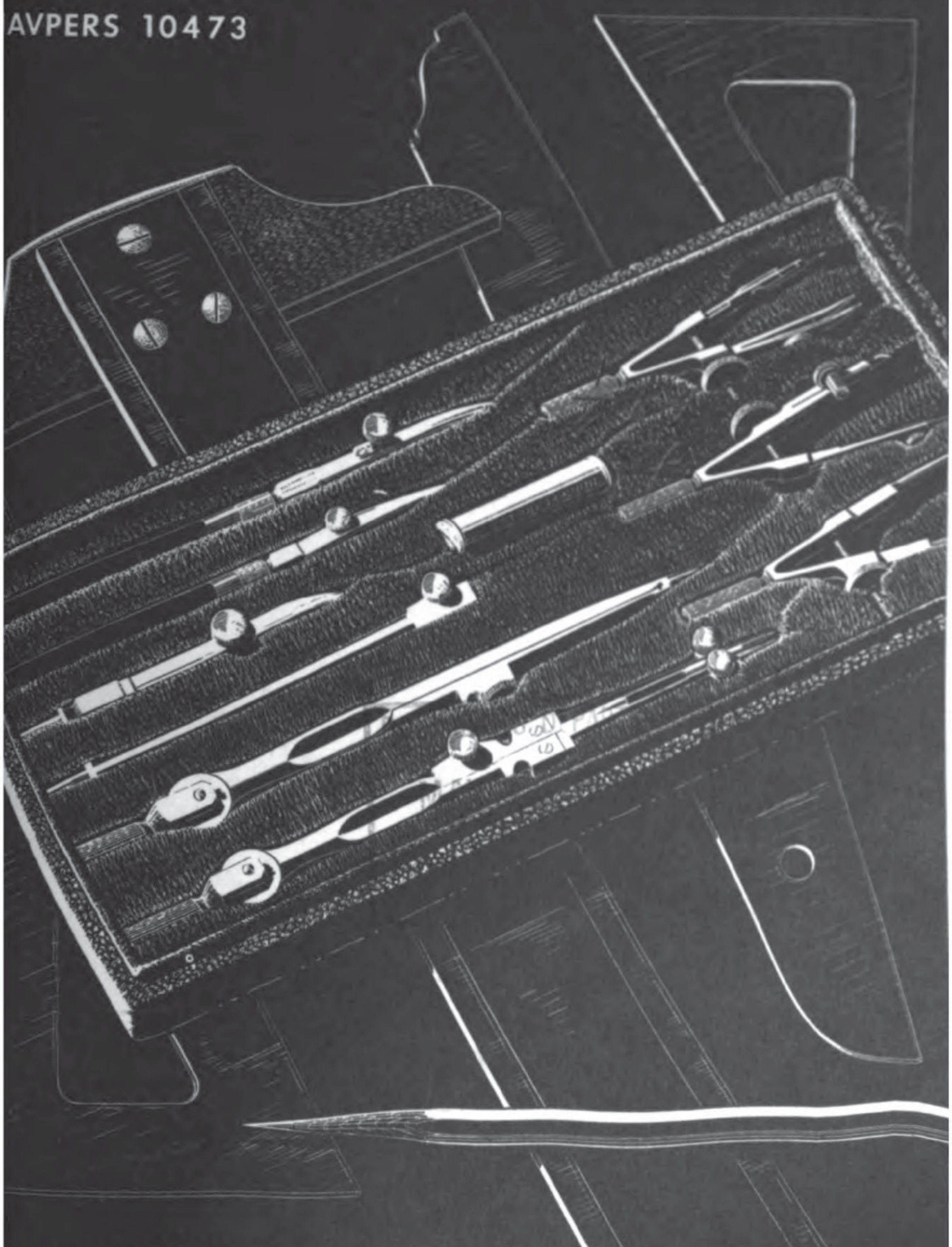
DRAFTSMAN 2

AVPERS 10473



AVY TRAINING COURSES

DRAFTSMAN 2

Prepared by
BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSES

NAVPERS 10473

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PREFACE

This manual was written for men in the Navy and Naval Reserve who are studying for advancement to Draftsman 2. The qualifications for advancement are listed in appendix II. Because examinations for promotion are based on these qualifications, it is suggested that you refer to them as you read the text in order to fix in your mind those portions of the text which cover examination subjects. The study guide following this preface will help you select the chapters of the book which are applicable to your rating.

A copy of the chart, "Approaches to Port Atlantis, H. O. Misc. 15,475–25–1," is distributed in a separate envelope with each copy of this manual. If you are a draftsman in the regular Navy or if your rating is a DMT or DML, study this chart carefully, referring to the discussions on map projections, the military grid, and map symbols in chapter 13 of this book. This is the type of chart which you may be called on to draw, or to make overlays for, in case of a national emergency.

This book was written with the assumption that the trainee will have read the basic Navy Training Courses, *Mathematics, Volume I*, NavPers 10069–A, *Mathematics, Volume II*, NavPers 10070–A, and *Electricity*, NavPers 10622–B. In order to answer some of the questions posed in this book, you will have to read these courses.

As one of the NAVY TRAINING COURSES, this book was prepared by the U. S. Navy Training Publications Center, with the assistance of the U. S. Navy Hydrographic Office and the Bureau of Yards and Docks, for the Bureau of Naval Personnel.

STUDY GUIDE

The table below indicates the chapters of this book you should study. To use it, select the column which applies to the rating for which you are striking. If you are in the regular Navy, use the column headed DM, which is the general service rating to which every chapter of this book applies. If you belong to the Reserve, use the column headed by your particular emergency service rating, either DMM (Mechanical Draftsman), DMS (Structural Draftsman), DME (Electrical Draftsman), DMT (Topographic Draftsman), DML (Lithographic Draftsman), or DMI (Illustrative Draftsman).

It is well for a man in any of the emergency service ratings to have an idea of the duties of the general service rating. Consequently, although a chapter may not apply to your particular duties, it will do you no harm to read it. But you should make a close study of the designated chapters, because they apply to qualifications which you must meet for advancement. These qualifications are listed in appendix II. The answers to the quizzes at the end of the chapters are given in appendix I.

Chapter	DM	DMM	DME	DMS	DMT	DML	DMI
1	x	x	x	x	x	x	x
2	x	x	x	x	x	x	x
3	x	x	x	x	------	------	x
4	x	x	x	x	x	------	------
5	x	x	x	------	------	------	------
6	x	x	------	------	------	------	------
7	x	x	------	------	------	------	------
8	x	x	------	------	------	------	------
9	x	x	x	------	------	------	------
10	x	x	x	x	------	------	------
11	x	------	------	x	x	x	------
12	x	------	------	------	x	x	x
13	x	------	------	------	x	x	------
14	x	------	------	------	------	x	------
15	x	------	------	------	------	------	x

READING LIST

NAVY TRAINING COURSES

Surveyor 3 & 2, NavPers 10632–B
Constructionman, NavPers 10630–A
Machinery Repairman 3 & 2, NavPers 10530
Machinist's Mate 3 & 2, NavPers 10524–A
Blueprint Reading, NavPers 10077
Electricity, NavPers 10622–B
Basic Machines, NavPers 10624
Mathematics, NavPers 10069–A
Mathematics, NavPers 10070–A

OTHER PUBLICATIONS

Military Standards, as appropriate

ARMY TECHNICAL MANUALS

5–230 *Topographic Drafting.*
5–232 *Elements of Surveying.*
5–241 *The Universal Grid Systems.*

USAFI TEXTS

United States Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to the DM rating follows:

MA 151 or CA 151 *General Mathematics I.*
MA 152 or CA 152 *General Mathematics II.*
MB 176 or CB 176 *Plane Geometry I.*
MB 177 or CB 177 *Plane Geometry II.*

*Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders.

MA 188 or CA 188	*Trigonometry.*
MB 767 or CB 767	*Commercial Art.*
MA 779	*Blueprint Reading.*
MA 769 or CA 769	*Mechanical Drawing.*
MB 772 or CB 772	*Elementary Architectural Drawing.*

COMMERCIAL TEXTS

GIESECKE, FREDERICK E., MITCHELL, ALVA, and SPENCER, HENRY CECIL. *Technical Drawing.* New York: MacMillan Co. 2nd ed.

FRENCH, THOMAS E. *Engineering Drawing.* New York: McGraw-Hill Book Company, Inc. 7th ed.

RAISZ, ERWIN. *General Cartography.* New York: McGraw-Hill Book Company, Inc. 2nd ed.

ROTMANS, ELMER A. *Drafting Simplified.* Albany, New York: Delmar Publishers, Inc. 1950.

CONTENTS

Draftsman 2

CHAPTER 1

HOW YOU FIT IN

PURPOSE OF THIS BOOK

Candidates for advancement in rate or rating are required to complete any applicable training courses. That means that in order to advance to Draftsman 2, all DM3's must complete this training course. This book is actually meant for two rates. It is a reference manual for the use of Draftsman 2, and it is a course of study for the Draftsman 3 who wants to become a Draftsman 2. At any time after advancement to Draftsman 3, a man may commence study on the course.

If you are a DM3 in the regular Navy, study the entire book. In the peacetime Navy, training programs are geared to produce broadly qualified, versatile men, who in time of emergency can assume positions of responsibility and authority. As you are rotated in duty within and among naval activities, you should strive to acquire maximum variety in experience and training.

If you are a draftsman in the Naval Reserve, you are in one of the emergency ratings. The study guide in the front of this book is designed for your use. In time of emergency, you will be required to perform the duties of your specialty. However, although you may study only the chapters in this manual which apply to your rating, you would do well to read the other chapters to get an overall picture of drafting in the Navy.

The purpose of this book is to present the fundamentals of what you should know as a Draftsman 2, but this book contains only the fundamentals. No single book could cover

all the ground, and regardless of how many books you read on the subject, nothing can substitute for actual experience. The skills you have developed came not from books but from actual manipulation of drafting tools and equipment.

Books sometimes help one understand a tool or an operation, and they organize knowledge and explain it. Unorganized knowledge may often be useful, but organized knowledge is clearly essential to success, no matter where you work. This book is meant to help you organize what you already know. In addition, it will tell you a few things you don't know.

You must know your business. You've been told dozens of times that a petty officer is first of all a leader and secondly a specialist. The two are not divorced; you are a leader in your specialty, too, or you wouldn't be where you are. You are responsible for attaining a high degree of proficiency in all the general qualifications of petty officers as well as in all the qualifications of a draftsman of your rate.

As a petty officer, you have certain military duties, and, as a specialist, certain technical duties. This book is not concerned with the former. Your military duties are explained, to some extent, in the *General Training Course for Petty Officers*, NavPers 10055. Wherever your duties are discussed in following chapters, the reference is to your specialist duties.

REQUIREMENTS OF THE JOB

Since the type of activity to which you may be assigned cannot be foreseen, this book does not go deeply into detail about the requirements of any specific assignment. Instead, it deals in a general way with your duties in various assignments. You may already have been assigned to more than one of the draftsman billets. Your type of duty will depend to a certain extent upon whether you are assigned to a ship or to a shore based activity.

Mechanical Drafting

Mechanical drafting covers a wide field. As a mechanical draftsman, you may be assigned to a repair ship or a construction battalion. You may make drawings of machines, of heating and ventilating or piping systems, or you may be required to draw repair parts for airplanes or ships. You should know how to draw isometric, oblique, and cabinet drawings, as well as drawings using third-angle orthographic projection. As a second class man, you must be prepared to make assembly drawings, as well as detail drawings.

You should know how to develop surfaces, working either on the actual material or on paper, and you must be able to make accurate working drawings. You should know how to dimension drawings, and understand how to indicate tolerance and surface roughness. You should know enough about machining processes to understand the terminology used on machine drawings. You should know enough about airplane structure and materials to understand the language involved. And you should be able to make takeoffs and bills of material from drawings.

Structural Drafting

As a structural draftsman, you will be required to make architectural layouts and structural drawings for light wood frame, heavy timber, and steel structures, including foundation and footings. You should know the properties of the common structural materials and their common uses and be able to make takeoffs, draw up bills of material, and assist in preparing specifications. You should also know the methods used in surveying for construction work and the types of drawings which may be required.

Electrical Drafting

As an electrical draftsman, you should be able to draw both schematics and wiring diagrams; understand how electricity and electromagnetism work; and know the parts of the common electrical machines and devices and the prin-

ciples on which they operate. You should also be able to draw electrical layouts for structures and make takeoffs of electrical materials and equipment.

Topographic Drafting

As a topographic draftsman, you will be expected to understand the characteristics and uses of the Mercator projection and of the military grid. You should be able to delineate topographic and hydrographic features. You must know the coordinates of the earth, the distances on a sphere, and the position of the poles, the equator, and the Greenwich meridian. You must know how to scale geographic features and the distinction between graphic and numerical or natural scales.

You should also know elementary surveying procedures, and surveying terms and instruments. You should know how to reduce surveying notes to a form suitable for drafting and how to interpolate contours. You should know how to make topographic drawings, including profiles and cross sections from notes. You must know how to use tide and current tables and how to determine local magnetic change and annual change from the World Variation Charts.

Lithographic Drafting

As a lithographic draftsman, you should be able to prepare tint plates and to make drafting changes on lithographic plates, using the proper materials and procedures for etching and counter-etching. You must know how to draw topographic and hydrographic symbols and how to match various styles of lettering, including gothic, roman, and italic. You should also be able to retouch negatives using lithographic needles and other materials.

Illustrative Drafting

As an illustrative draftsman, you should be able to do layouts for publications and posters. You should know something about type faces, how to choose them, and how to mark and key copy for the printer. You should know

how to letter in gothic, roman, italic, Old English, and script.

You should be able to plan and render finished illustrations. And in order to do this, you should understand the principles of perspective, know how to indicate form by shading, and be able to draw the human figure in proportion and in lifelike positions.

You should also know how to mix colors, how to create pleasing color schemes, and how printing processes limit the use of color.

ADVANCEMENT IN RATING

The requirements for advancement in rating are spelled out in the *Manual of Qualifications for Advancement in Rating* and in various BuPers instructions. The following is a brief summary of the requirements for advancement to Draftsman 2.

1. You must have been a Draftsman 3 for 12 months.
2. You must have met certain requirements as to marks in proficiency in rate and in conduct.
3. You must have completed satisfactorily the Navy training course for Draftsman 2.
4. You must have qualified fully in the practical factors for the rate of Draftsman 2.
5. You must have been considered by senior petty officers and officers as capable of performing the duties of the higher rate and have been recommended by your commanding officer.
6. You must have passed an examination on the military requirements for the E–5 pay grade and the professional qualifications for the rate of Draftsman 2 as prescribed in the *Manual of Qualifications for Advancement in Rating*, NavPers 10068.

This may sound like a long obstacle course when you start out, but taking each thing in turn, you will find that it can be done without too great a push. There will always be plenty to learn about drafting. No good draftsman ever stops learning. Learning about methods and materials already in

existence and keeping up with new ones require a high degree of concentrated effort.

Study all available publications dealing with the type of work you are assigned to do. Related publications are listed in the various chapters. Discussions of the military standards on drafting and on the use of engineering handbooks and similar reference books follow.

DRAFTING STANDARDS

Military standards for engineering drawings and for illustrations for technical manuals are published with JAN–STD or MIL–STD publication numbers. If you have not already obtained these or if your copies are out of date, make every effort to obtain recent copies. The following table gives the number, title, and date of the current publications dealing with drafting standards:

Number	*Title*	*Date*
JAN–STD–1	General drawing practice	13 May 48
MIL–STD–2A	Drawing sizes	22 Aug 49
MIL–STD–3A	Format for production drawings	26 Sep 52
MIL–STD–4A	Format for construction drawings	4 Sep 52
MIL–STD–8A	Dimensioning and tolerancing	5 Jun 53
MIL–STD–10	Surface roughness, waviness, and lay.	2 Aug 49
MIL–STD–12A	Abbreviations for use on drawings	11 Mar 52
JAN–STD–14	Architectural symbols	23 May 49
MIL–STD–15A	Electrical and electronic symbols	1 Apr 54
MIL–STD–16A	Electrical and electronic reference designations.	18 Apr 52
MIL–STD–17	Mechanical symbols	6 Jul 50
MIL–STD–18A	Structural symbols	12 Aug 53
JAN–STD–19	Welding symbols	13 Nov 47
MIL–STD–20	Welding terms and definitions	14 Dec 49
MIL–STD–23A	Nondestructive testing symbols	25 Aug 52
MIL–STD–24	Revision of drawings	9 Mar 51
MIL–STD–103	Abbreviations (for electrical and electronic use).	18 May 53
MIL–STD–106	Mathematical symbols	16 Aug 51
MIL–STD–218–2	Technical manuals, part 2—production or procurement of artwork for technical manuals.	25 Jan 54

HANDBOOKS AND CATALOGS

Besides the military standards, you should have access to at least one good engineering handbook and know how to use it. Handbooks contain little more than a collection of formulas and tables with some illustrations and brief explanations—information which you could not remember in detail and which, in many cases, would be very tedious to compute.

A good understanding of the proper use of handbooks can go far toward making you a successful draftsman. Handbooks are prepared with the assumption that the user is already familiar with the principles connected with the given information contained in them. They are to be used as reference books, not for instruction. Rather than trying to collect a large number of handbooks, concentrate on learning well the use of the few that seem to fit your needs best.

In a project in mechanical, electrical, or structural design, the detail draftsman is often called upon to select certain standard items, such as bolts, bearings, rivets, keys, gears, couplings, pulleys, hinges, or locks. Usually the best source of information concerning such items is the catalog description.

Most of the material and articles with which you work will be supplied by the Navy and will be found in the *Catalog of Navy Material* or the Navy Stock List which constitutes part of the *Federal Supply Catalog*. These catalogs or stock lists identify all items of general supply carried in stock for issue to ships and stations. In addition to the lists describing general stores, special materials sections or lists have been prepared by each technical bureau of the Navy. These lists provide information concerning equipment and related repair parts which are not ordinarily used by other activities and bureaus. For instruction on the use of these lists or catalogs, you may consult the respective forewords. A discussion of their use may also be found in *Storekeeper 3 and 2*, NavPers 10269–B.

A neatly filed collection of the catalogs furnished by the

manufacturers of commonly used equipment is very useful. The catalogs of many manufacturers list data and include illustrations especially prepared for the use of detail draftsmen.

An *Index of Specifications and Standards, Used by Department of the Navy, Military Index*, Volume III, is issued twice a year on 1 April and 1 October, and cumulative monthly supplements are issued during the intervening months. These contain listings either by number or by title of Federal, Military, Navy Department, and Air Force–Navy Aeronautical Specifications, as well as Federal Standards.

QUIZ

1. How long must you have been a Draftsman 3 to be advanced to the Draftsman 2 rate?
2. What training course must you complete?
3. On what is the servicewide examination for advancement to the Draftsman 2 rate based?
4. What do engineering handbooks contain that will be of value to you?
5. Where are the Navy items of general supply listed?
6. Where can you find listings of Federal, Military, Navy Department, and Air Force-Navy Aeronautical Specifications, as well as Federal Standards?

CHAPTER 2

INSTRUMENTS AND EQUIPMENT

TOOLS FOR THE JOB

The common drawing instruments and equipment are described in *Draftsman 3*, NavPers 10471. You will do well to review chapters 2, 3, and 7 in that manual. In this chapter, more attention will be given to the selection and care of drafting instruments and equipment.

By this time, you will have learned from experience how important it is for you to work with good instruments and materials. If a man is a poor draftsman, the best instruments in the world will not make him a good draftsman. On the other hand, a good, competent man will do better work if he is furnished good instruments and materials, and since he knows the importance of good equipment, such a competent man will make every effort to keep it in good condition.

As a Navy draftsman, you are not expected to buy your own instruments. These are furnished by the Navy. If you have professional pride, you will care for them as you would your own. However, when an instrument is defective or worn beyond repair, do not hesitate to ask that it be replaced. Remember that the quality of your work is of first importance.

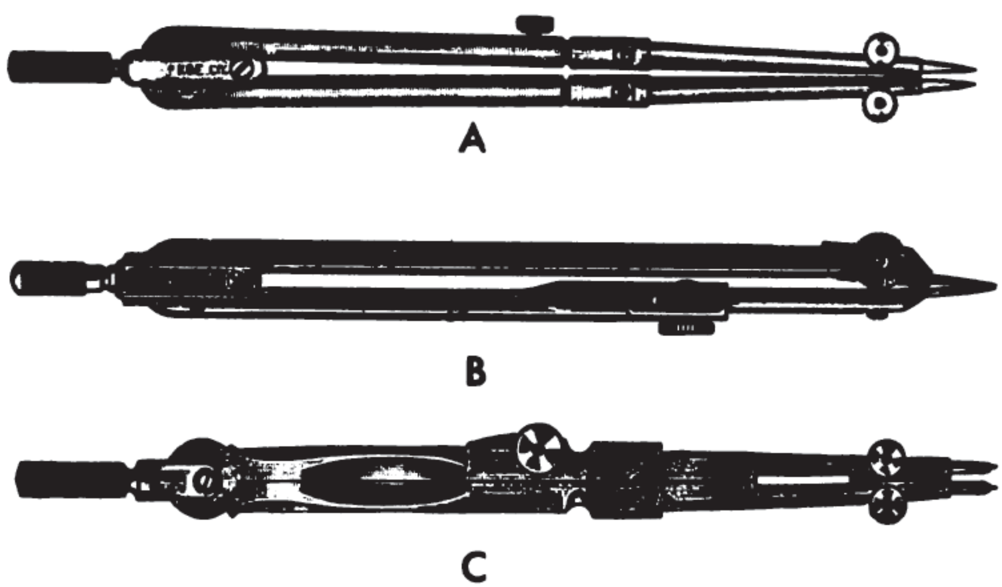
CASE INSTRUMENTS

Your instruments may be issued to you one by one or as a set in a case. If possible, it is best to keep them in a case, since the case protects them from falls or unnecessary pressures. Then, too, the lining of the case is usually treated

with a chemical which helps prevent the instruments from tarnishing or corroding.

To protect instruments from rusting when they are not in use, clean them frequently with a soft cloth and apply a light film of oil to their surface with a rag. Joints on compasses and dividers should not be oiled. A knife edge or an abrasive should never be used to clean instruments, since, when the surface finish is worn or scarred, they are more subject to corrosion.

It is sometimes difficult to judge the quality of drafting instruments by appearance alone. Often their characteristics become evident only after they are used. Usually,



Courtesy Keuffel & Esser Co.

Figure 2–1.—Shapes of compasses and dividers. A. Round. B. Flat. C. Bevel.

cheap quality instruments have a mass-production appearance, with little machine finishing and with designs that permit rapid assembly. On the other hand, high quality instruments are usually correctly sharpened, adjusted, and packaged in a good quality case when they come from the manufacturer. Some instruments, although accurately made and capable of fine adjustment, are lacking in rigidity. For this reason, the simple, sturdy instruments are often most

practical. Before you select instruments, look for the brand name and try to learn something about the reputation it has with experienced draftsmen.

Compasses and Dividers

Figure 2–1 shows the three common shapes in which compasses and dividers are made. They may be purchased in

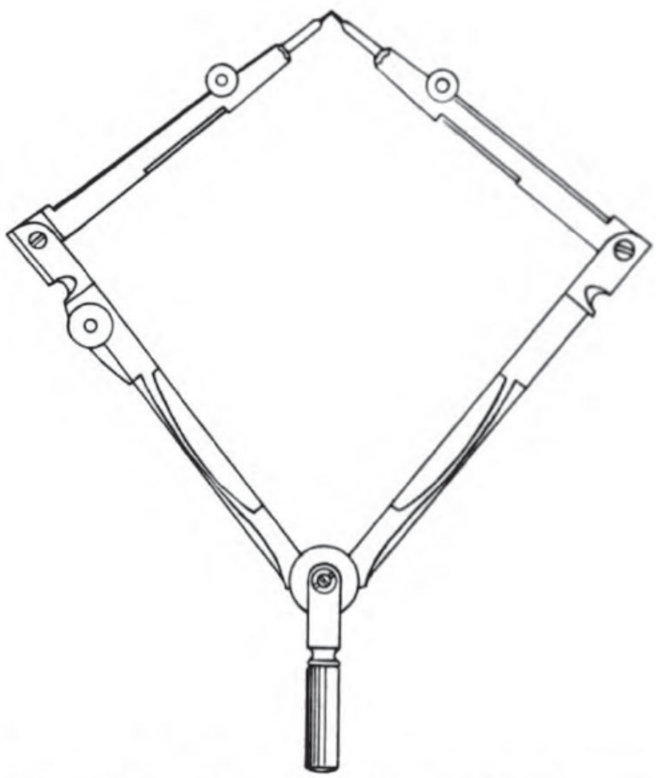
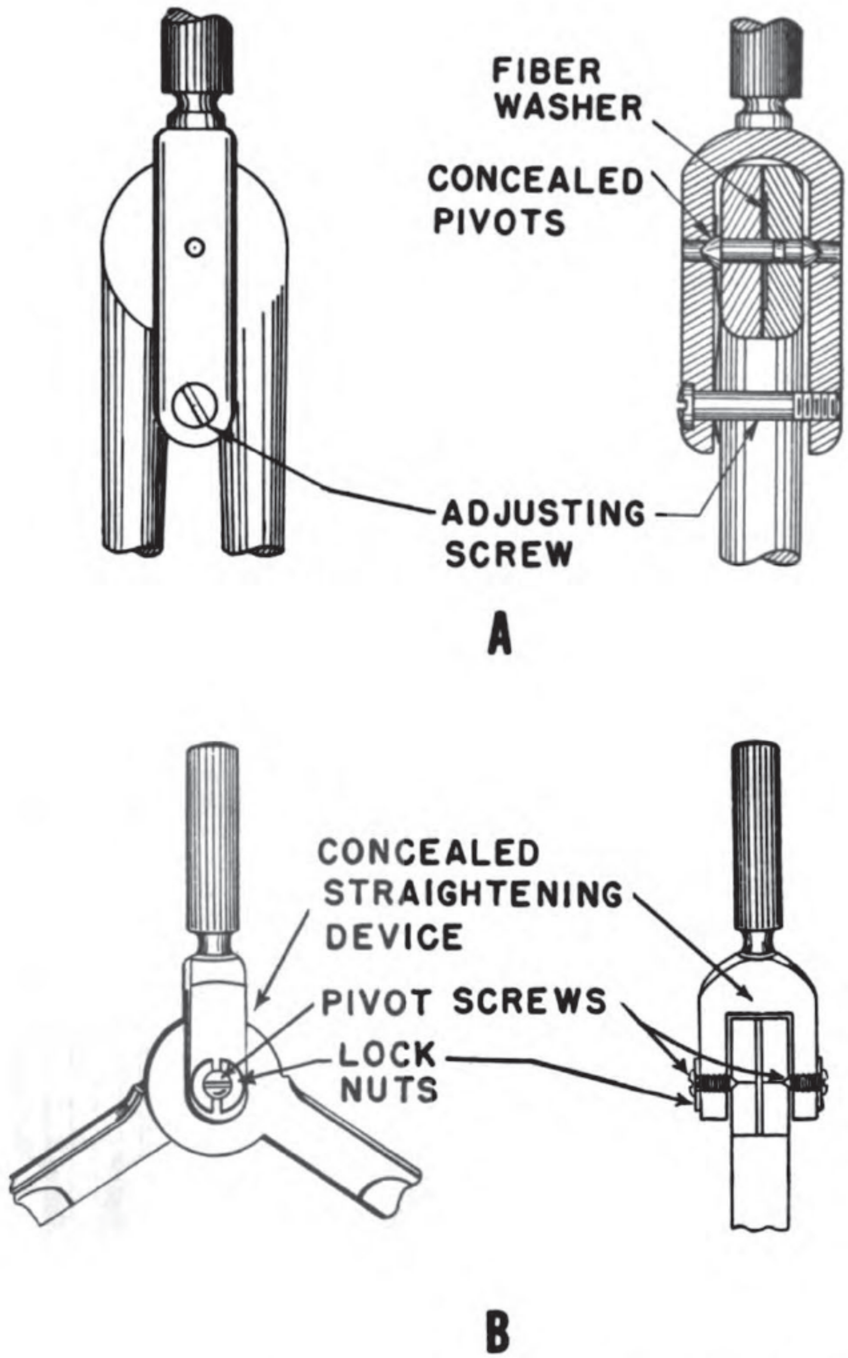


Figure 2–2.—Testing the compass for alignment.

Figure 2–3.—The tongue joint.

either the round, the flat, or the bevel shapes. When you select compasses and dividers, test them for alignment by bending the joints and bringing the points together, as shown in figure 2–2.



Courtesy Keuffel & Esser Co.

Figure 2–4.—Sections of pivot joints.

Older compasses and some cheap modern ones have a tongue joint. (See fig. 2–3.) Because there is no way to tighten this type of joint after it becomes worn, modern pivot joints are more satisfactory. Figure 2–4 shows types of pivot joints found on compasses and dividers.

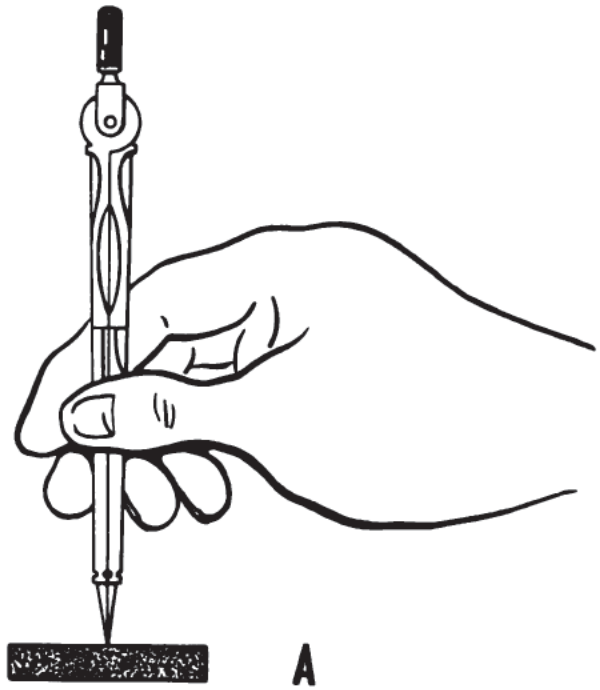
Dividers should be adjusted so that they may be set without undue friction. They should not be so rigid that their manipulation is difficult, nor so loose that they will not retain their setting. Hairspring dividers are set for the correct friction by skilled instrument makers, and it is inadvisable to attempt adjustments in the drafting room, since a special wrench is needed which is ordinarily not available.

Divider points should be straight and free from burrs. When the dividers are not in use, the points may be protected by sticking them into a small piece of soft rubber eraser or cork. When points have become dull or uneven in length, make them even by holding the dividers vertically, placing the legs together, and grinding them lightly back and forth against an oilstone. (See fig. 2–5A.) Then hold the dividers horizontally and sharpen each point by whetting the outside of it back and forth on the stone, while rolling it from side to side with your fingers. (See fig. 2–5B.) The inside of the leg should remain flat and should not be ground on the stone. Neither should any part of the outside of the point be ground so that a flat surface results. In shaping the point, be careful to avoid shortening the leg.

Needles on bow instruments and compasses should be kept sharpened to a fine taper. When they are pushed into the drawing, they should leave a small, round hole in the paper no larger than a fine line. Since the same center is often used for both the bow pen and the compass, it is best that needles on both be the same size. If the compass needle is noticeably larger, either use it without pushing it into the paper or grind it until it is the correct size. With some instrument sets, a special disk is provided for use when a hole in the paper at the center of a circle or arc is especially undesirable. This disk may be composed of plastic and

metal or of bone, and it has three sharp points around its outside diameter which, when they are pushed into the paper, hold the disk in position.

To make a compass needle smaller, wet one edge of the



A

B

Figure 2–5.—A. Making divider legs even. B. Sharpening divider points.

oilstone and place the needle with its shoulder against this edge. Then grind it against the oilstone, twirling it between your thumb and forefinger. (See fig. 2–6.) Test it for size

by inserting it in a hole made by another needle of the correct size. When it is pushed as far as the shoulder, it should not enlarge the hole.

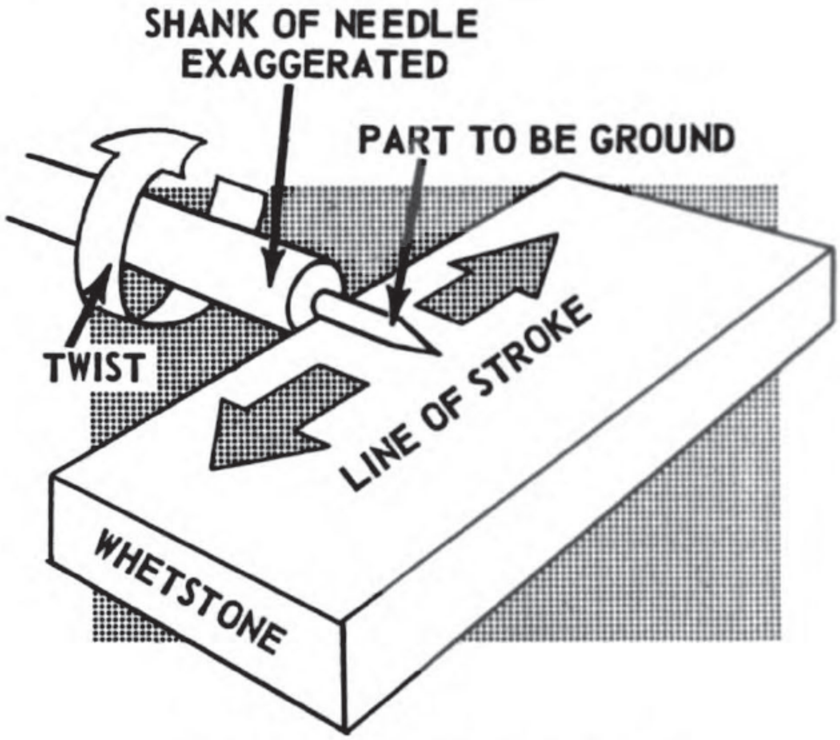


Figure 2–6.—Shaping a compass needle.

Sharpening the Ruling Pen

High quality is especially desirable in a ruling pen. If the nibs are of low quality steel, it will be more difficult to keep them sharp. A good pen will usually be sharp when it comes from the manufacturer, but a cheap pen may need sharpening before it is used.

When you start having difficulty drawing fine lines or getting the ink to flow from your pen, check it for signs of wear. Hold the nibs toward you in a good light, and if they are worn, you will see a bright spot on the tip of each nib which is not present on a sharp pen. This spot indicates a flat surface that has been formed by wear. (See fig. 2–7A.)

A ruling pen that has become dull may be sharpened on a fine oilstone if extreme care is used. To restore the nibs to

their original parabolic shape, hold the pen in a vertical plane and bring the blades into light contact with the stone. Then whet the pen back and forth through an angle of about

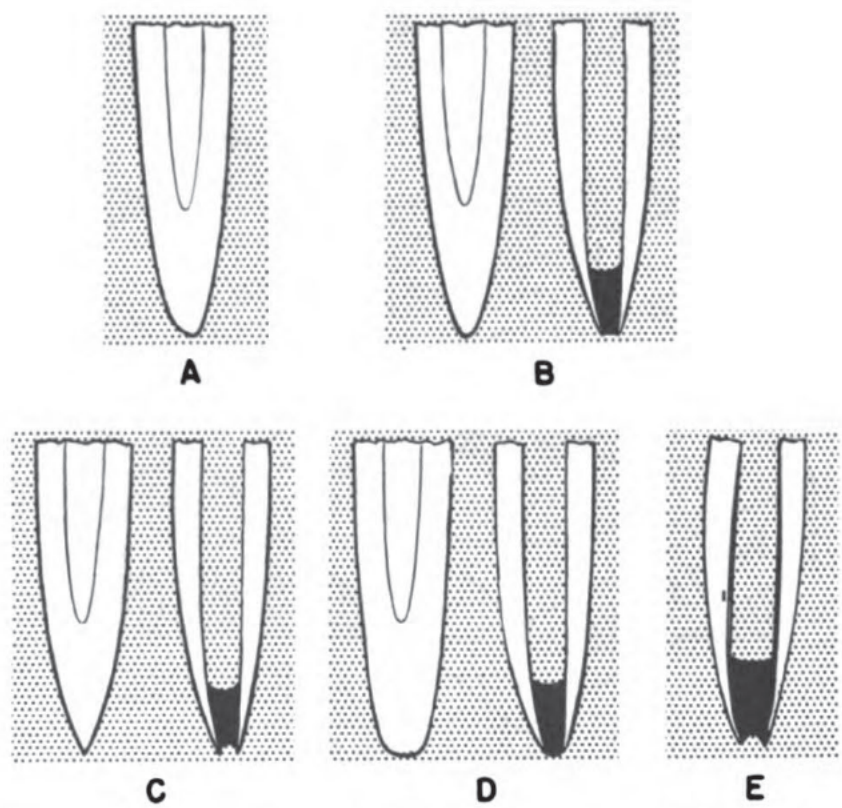


Figure 2–7.—Ruling pen nibs. A. Worn point. B. Correctly shaped point. C. Too pointed. D. Too blunt. E. Convexed inner surface.

120 degrees. (See fig. 2–8.) To sharpen each nib of the pen, hold the outside surface nearly flat on the surface of the oilstone and whet with a rotary motion to conform to the shape of the nib. (See fig. 2–9.)

Take care not to alter the parabolic shape of the ends. The edges should not be too sharp or they will cut the paper when the pen is used. Any burr should be removed from the inside of the blades with a piece of leather or emery paper. The inside surface should never be stoned, since stoning may give it a slight convexity, which is very undesirable.

There is another method of sharpening ruling pens which requires less skill. Place a fine grain emery paper on a base of sponge rubber or a towel folded several times. Shape the ruling pen on the emery surface just as you would shape it

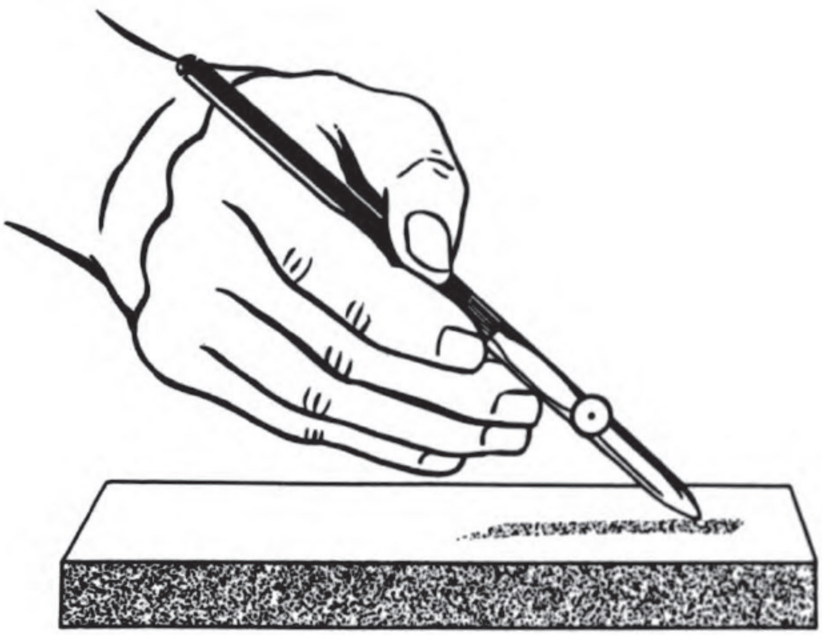


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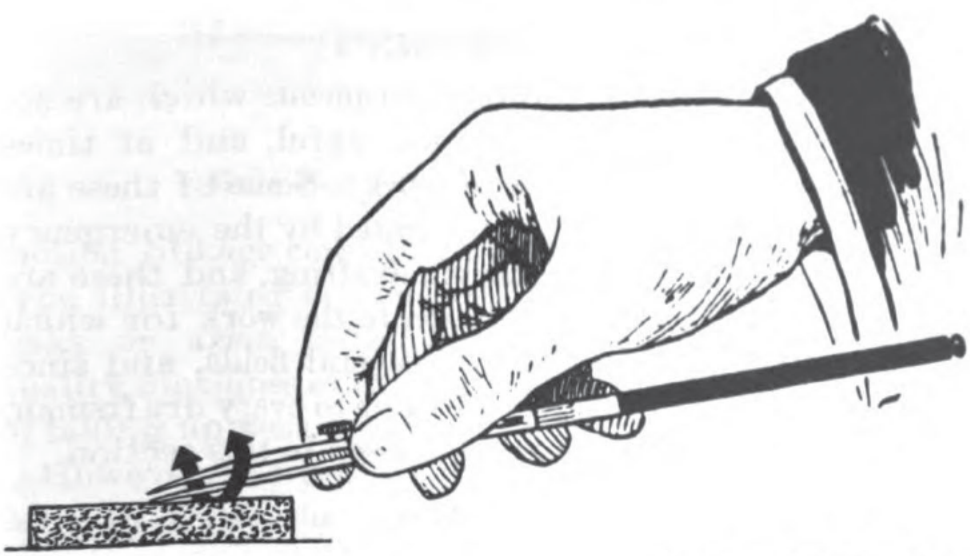
Figure 2-8.—Shaping the ruling pen.



Courtesy Eugene Dietzgen Co.

Figure 2-9.—Sharpening the ruling pen.

on an oilstone. Then open the nibs and place the back of each one in turn at an acute angle in full contact with the surface of the emery paper. (See fig. 2–10.) Draw the pen repeatedly over the surface of the emery paper, always in a direction toward the handle of the pen and with sufficient downward pressure so that the paper becomes de-

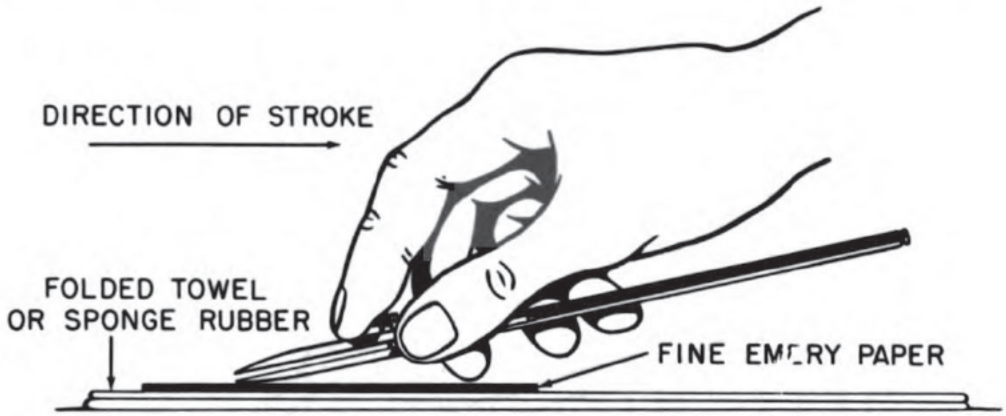


Figure 2–10.—Sharpening the nibs of a ruling pen on emery paper.

pressed into a channel fitting the contour of the nibs. Hold the pen firmly and prevent it from turning, so that the edges of the nibs are in equal contact with the paper. When the nibs are sharp enough, grind the inside surface lightly with the emery paper to remove any burrs that may have formed.

SPECIAL INSTRUMENTS

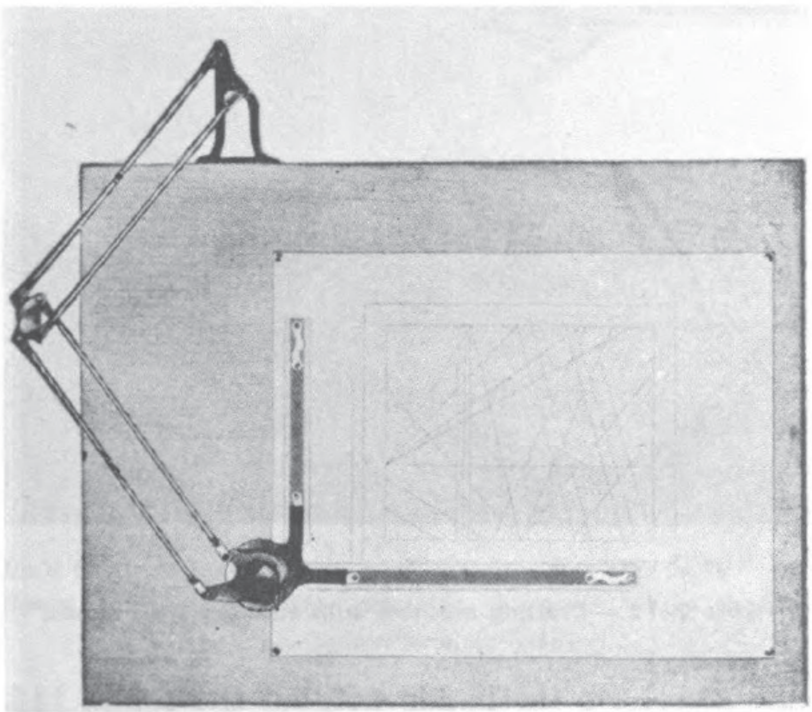
There are a number of drafting instruments which are not always required but which are very useful, and at times indispensable, for certain types of work. Some of these are used in only one of the fields represented by the emergency service ratings, such as topographic drafting, and these are discussed in later chapters in relation to the work for which they are used. Others are used in several fields, and since a general knowledge of these are of value to every draftsman, their selection, use, and care are discussed in this section.

Drafting Machines

The drafting machine combines the functions of a parallel ruler, simple protractor, and scale. Any drafting operation

requiring straight parallel lines may be performed advantageously with a drafting machine. Since these machines are expensive, they are not used except where work is constant and speed highly important.

The majority of drafting machines are constructed so that a protractor head may be moved over the surface of a drafting table without change in orientation by means of a parallel

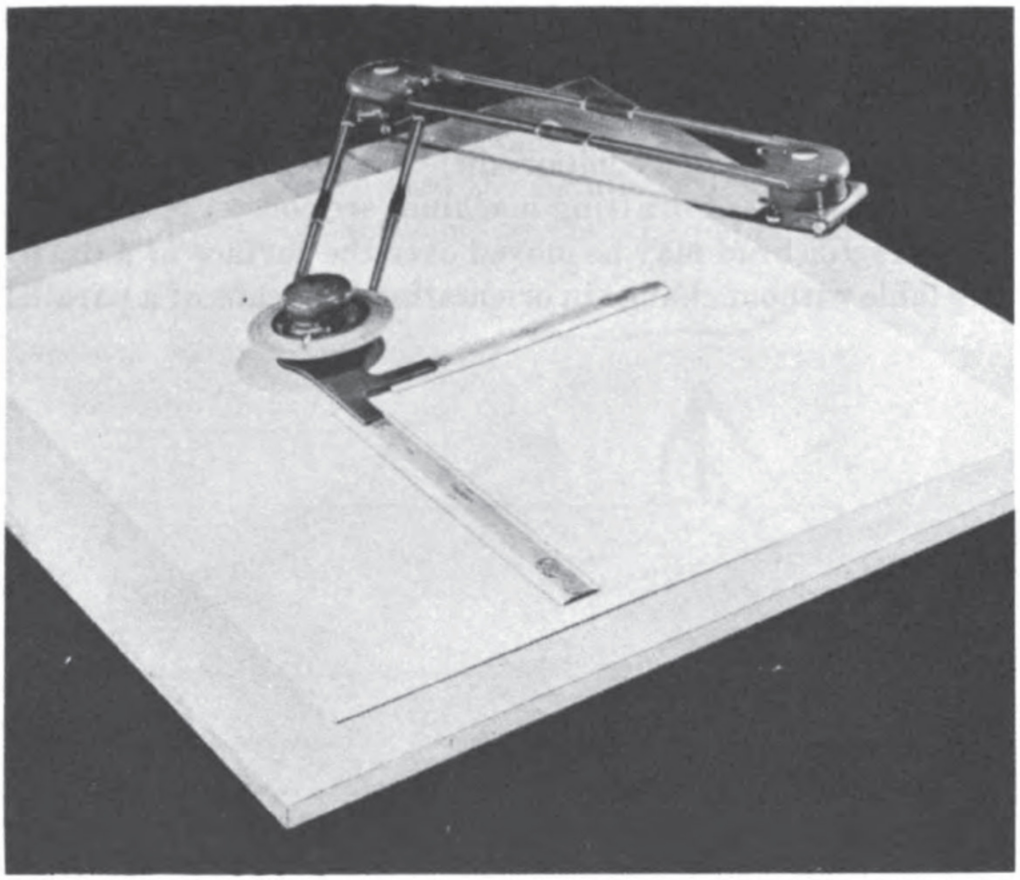


Courtesy Eugene Dietzgen Co.

Figure 2–11.—Drafting machine with rigid arms.

motion linkage consisting of two sets of double bars. The type illustrated in figure 2–11 has rigid metal connecting links or arms, called pin-joint linkage. On the better quality machines of this type, the bearings will have a means of taking up wear.

However, the type of drafting machine shown in figure 2–12, in which the linkage is provided by two steel bands working against one another, is superior to that with pin-joint linkage, because there is less lost motion. The machine in figure 2–12 has steel bands enclosed in tubes, although this



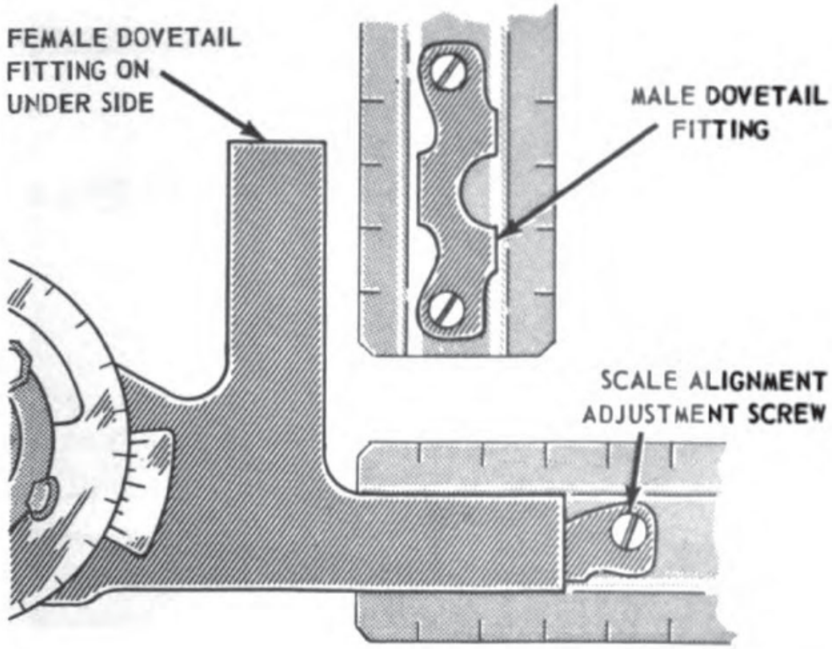
Courtesy Universal Drafting Machine Co.

Figure 2–12.—Drafting machine with enclosed steel bands.

type may also have the bands without the tubes. If these bands become loose through wear or expansion, the tension may be increased on them, although this is seldom necessary.

The protractor head is a complete circle, graduated in degrees, to which a straightedge or scale may be clamped at any desired angle. If desired, two scales may be attached to the head at right angles to each other. The method of attaching these scales has been fairly well standardized so that a wide variety of scales can be attached or removed as desired. Tapered, dovetailed fittings, with the female part on the control head and the male part on the rule, connect the scales to the drafting machine. (See fig. 2–13.) To remove a scale, a key is used which fits over the head of the adjusting screw. The key, by cam action, pushes the dove-

tailed fittings far enough apart so that the scale can be removed by hand. To insert a scale, carefully slide the dovetails into place and tighten them by tapping lightly with the palm of your hand.

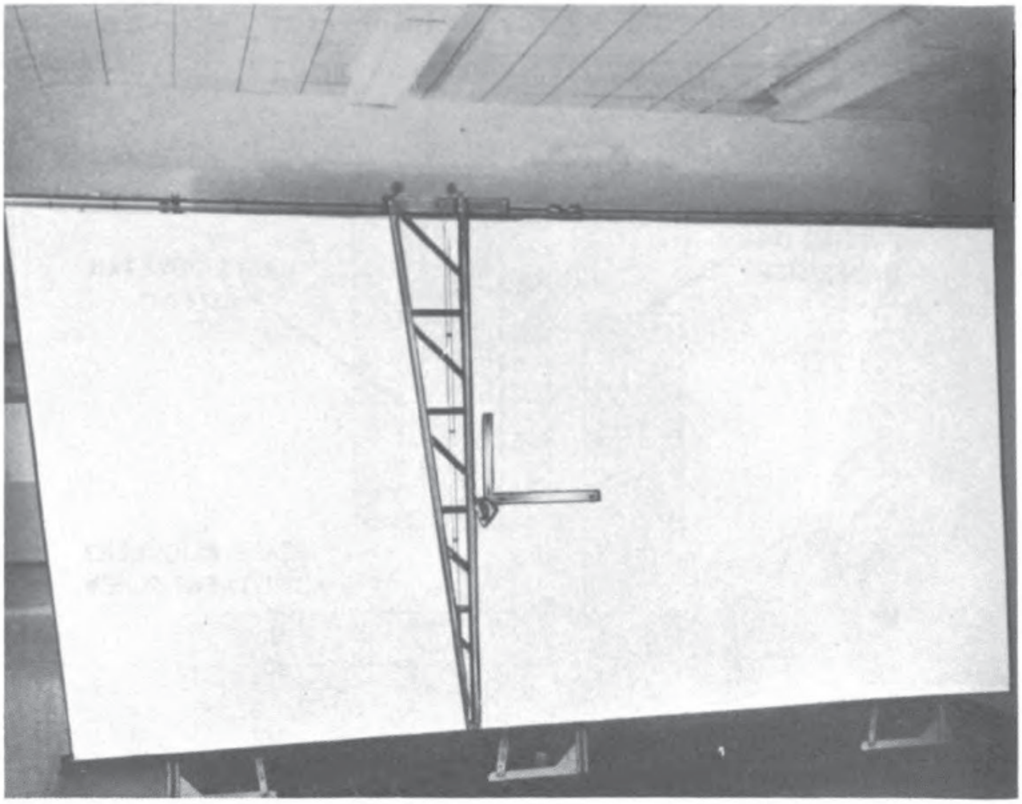


Courtesy Cooper Trent

Figure 2–13.—Fittings for attaching the scale to the drafting machine.

One of the screws holding the fittings to the scale passes through an elongated slot, which allows for some angular adjustment of the scale. This adjustment is for truing the two scales with each other. To adjust them, draw a line by the horizontal scale. Swing the scales 90° clockwise. The scale that had been vertical should now be horizontal and should fit exactly by the line just drawn. If it does not, loosen its adjustment screw, set it right, and then tighten the screw. You will then have the two scales set at a 90° angle to each other.

Correct alignment of the scales with the board is usually accomplished by some adjustment in the control head or linkage of the machine. Any major repairs or adjustments on a drafting machine should be done by an instrument repair man and not attempted in the drafting room.



Courtesy Emmert Manufacturing Co.

Figure 2–14.—Roller-type drafting machine.

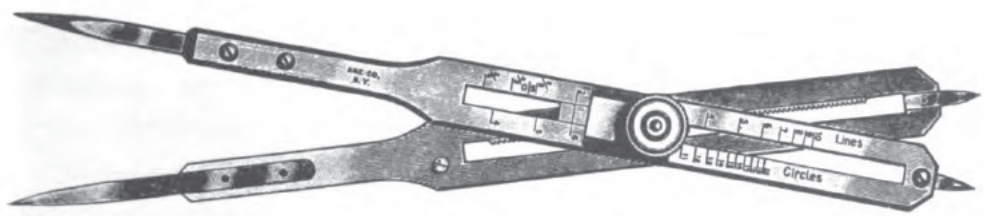
Figure 2–14 shows a type of drafting machine in which the scales are moved horizontally or vertically by means of rollers on tracks. This type of machine has special advantages when it is used on extra large drawing boards. Angular adjustments can be made to within 1 minute on some of these machines.

Proportional Dividers

Proportional dividers are convenient for transferring measurements from one scale to another when drawings are to be made to a larger or smaller scale. (See fig. 2–15.) They can also be used to divide lines or circles into equal parts or to get some special ratio such as $1:\sqrt{2}$ or feet to meters.

They consist of two legs of equal length, pointed at each end and held together by a movable pivot. By varying the

position of the pivot, the lengths of the legs on opposite sides of the pivot may be adjusted so that the ratio between them is equal to the ratio between two scales. Therefore, a distance spanned by the points of one set of legs has the same relation



Courtesy Keuffel & Esser Co.

Figure 2–15.—Proportional dividers.

to the distance spanned by the points of the other set as one scale has to the other.

A thumb nut moves the pivot in a rack-and-gear arrangement. When the desired setting is reached, a thumb-nut clamp on the opposite side of the instrument locks the pivot in place. A scale and vernier are provided on one leg to facilitate accurate setting. The dividers may be set by reference to the table of settings which is furnished with each pair; they will accommodate varying ranges of scales up to 1 to 11.5. However, it is better not to depend entirely on the table of settings. You can check the adjustment by drawing lines representing the desired proportionate lengths and then applying the points of the instrument to them in turn, until by trial and error the correct adjustment is reached.

To divide a line into equal parts, set the dividers to a ratio of 1 to the number of parts desired. For instance, to divide a line into 3 parts, set at 3 on the scale. To use the dividers to transfer measurements from feet to meters, draw a line 1 unit long and another line 3.28 units long and set the dividers accordingly. To get the ratio of $1:\sqrt{2}$, draw an isosceles right triangle and set the dividers to a ratio of the length of the hypotenuse to the length of either of the equal legs. Some proportional dividers have an extra scale for use in getting circular proportions.

The points of the dividers are of hardened steel, and if they are handled carefully these points will retain their sharpness during long use. If they are damaged, they may be sharpened and adjusted without affecting the accuracy of the instrument, but the table of settings will no longer be exact.

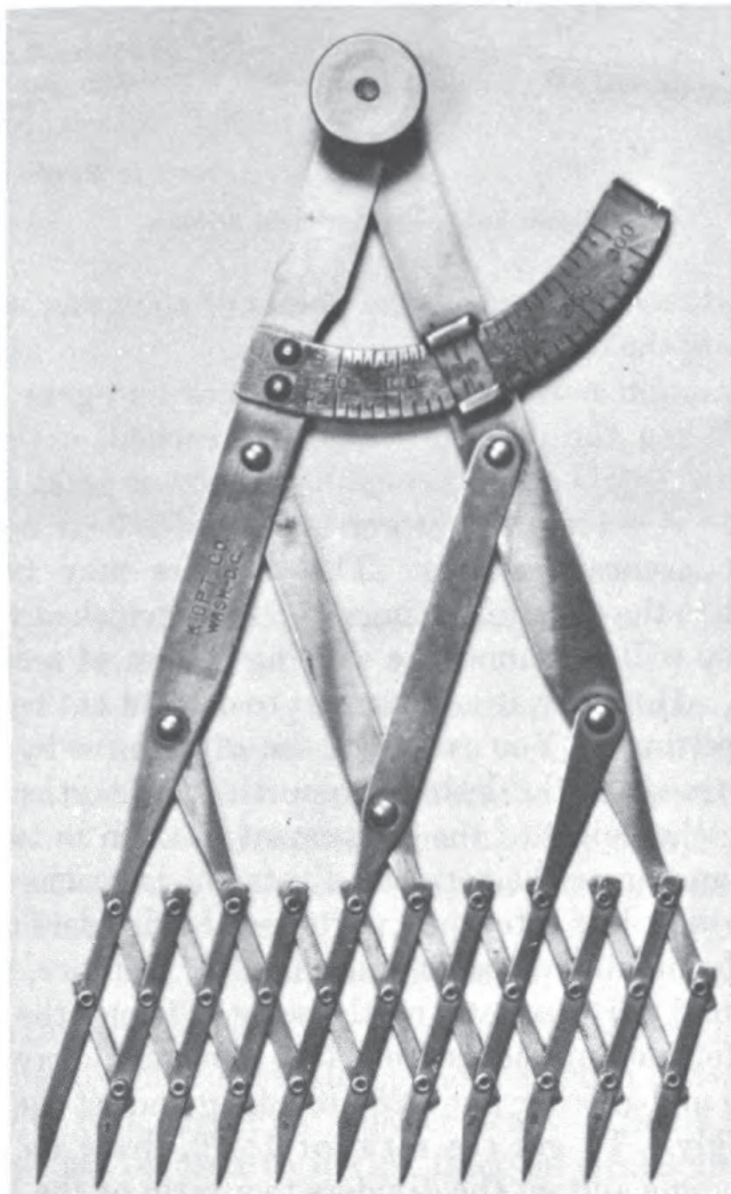


Figure 2–16.—Spacing dividers.

Spacing Dividers

Spacing dividers are constructed with multiple legs arranged so that they subdivide the total distance spanned into a number of equal parts. (See fig. 2–16.) The size most frequently used is about 6 inches long and contains 11 points numbered consecutively from 0 to 10. With these dividers, distances up to 9 inches in length may be divided into 10 equal intervals.

Spacing dividers should not be handled roughly, and particular care must be taken to ensure that the points are not injured or bent. If the pivot becomes too loose or too tight, the instrument should not be used.

OTHER EQUIPMENT

The items discussed in this section are in general use, and you may have learned as much or more than is stated here concerning them. The descriptions and suggestions, therefore, are included here for those who have not had the opportunity to pick up these facts in practice.

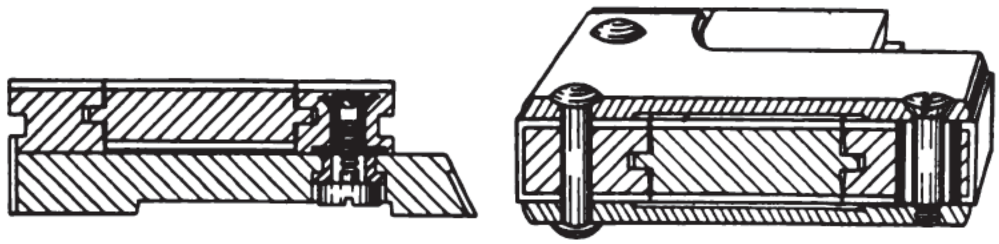
Slide Rule

The standard type of slide rule is made of mahogany, or some other hard, moisture-resistant wood, which has been carefully selected, cured, and treated so that it will be affected as little as possible by atmospheric changes and moisture. The surface is usually white celluloid about $\frac{1}{32}$ of an inch thick. The numbers and graduations are usually printed in black ink. Occasionally one scale is printed in red to distinguish it from another. In the last few years, metal slide rules have also become popular.

In order to function well, the two slides of the rule and the indicator should all move smoothly and in correct relation to other parts. Slide rules may become too loose or too tight because of wear, absorption of moisture, or the drying of the wood. Therefore, practically all of the better-grade slide rules have some means of adjusting the slides and the indicator. In figure 2–17, two types of slides are illustrated

in cross section, showing the adjustment screws. If it is necessary to adjust either of these rules, first loosen the screws; then shift the guide piece toward or away from the slide until it is tightened or loosened to produce the desired friction. Then tighten the screws again.

When a slide rule is correctly adjusted, the right and left indexes on all scales, and on both sides if it is a two-sided



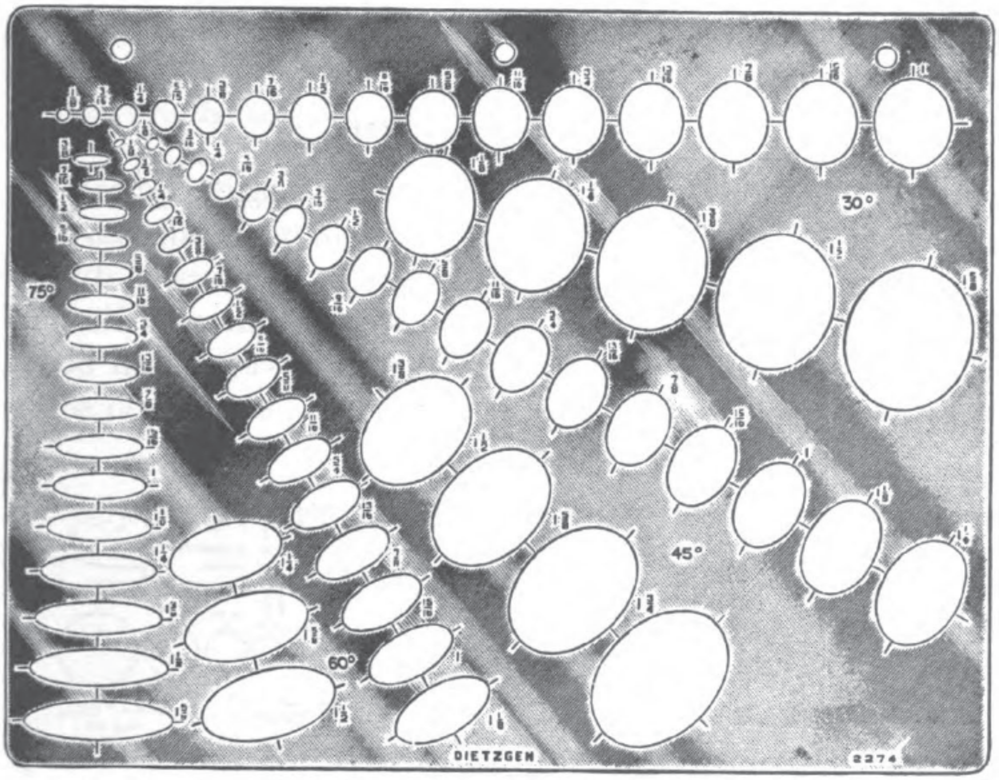
Courtesy Keuffel & Esser Co.

Figure 2–17.—Cross sections of two types of slide rules.

rule, should line up. The slide should move freely at any position, but it should also have sufficient friction to remain in place after it is set. In selecting a slide rule, check the indexes and the movement, and then set the hairline on the indicator to varying proportions or square roots, such as 2 on the D scale with 4 on the A scale.

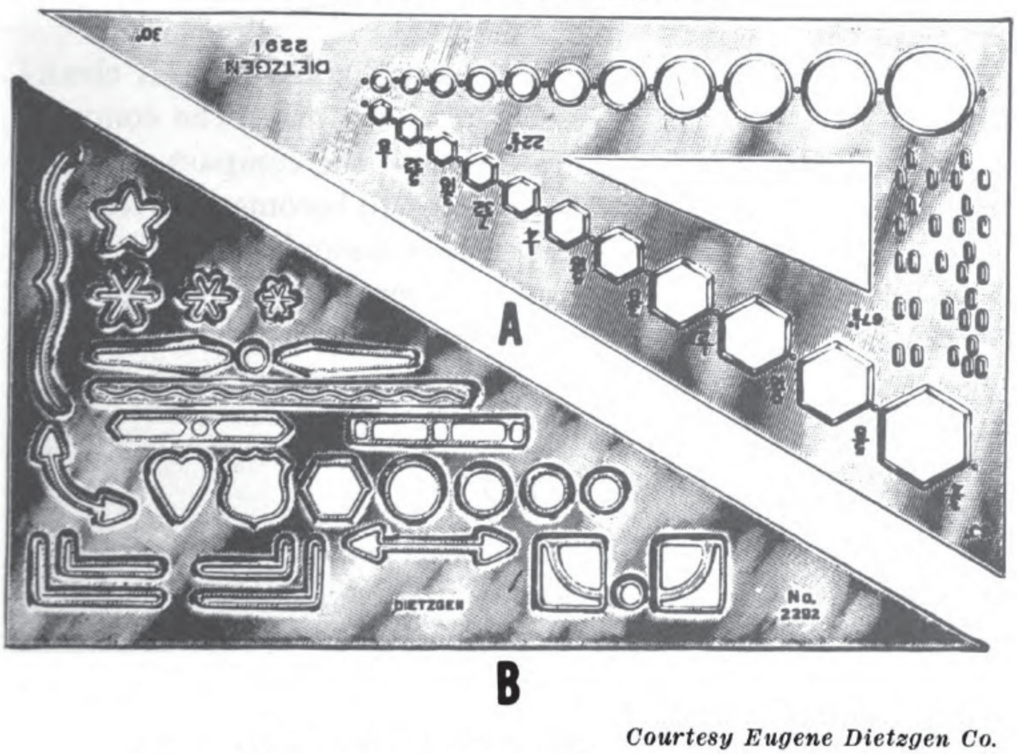
Templates

You can save a great deal of time on jobs on which the same shape or symbol is to appear a number of times by using templates. Most of the templates on the market are made of transparent plastic and offer a wide variety of shapes, including ellipses, hyperbolas, circles, hexagons, and arcs. There are special templates for symbols and shapes used in drawings of electrical and chemical apparatus, bolt heads and nuts, architectural drawings, and decorative designs. (See figs. 2–18, 2–19, and 2–20.) If the shape you need is not available, it may be worth your while to take time to make



Courtesy Eugene Dietzgen Co.

Figure 2–18.—Ellipse template.



B

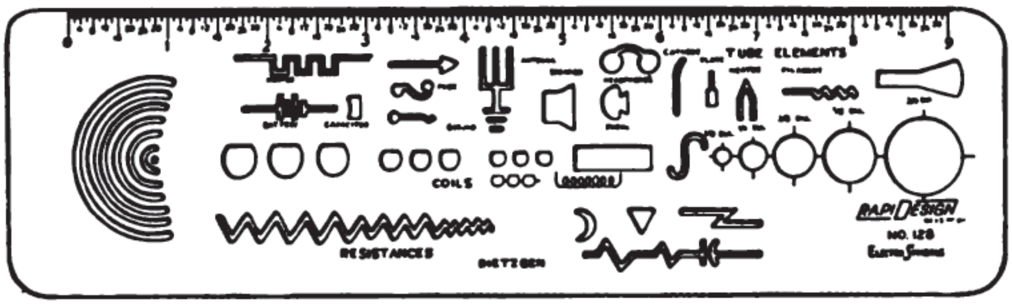
Courtesy Eugene Dietzgen Co.

Figure 2–19.—A. Engineer's triangle. B. Design triangle.

your own template from cardboard, plastic, lead, or some other sheet metal.

Drawing Board Covers

It is common practice to cover drawing boards, especially the larger and more expensive ones, to ensure cleanliness and to protect them against nicks and scars. A desirable drawing board cover is made of some material that will lie flat with a minimum of puckers. It should have enough body to provide protection; it should not be too hard or too soft;



Courtesy Eugene Dietzgen Co.

Figure 2–20.—Electrical symbol template.

and it should be strong enough to withstand several cleanings before being renewed. If it is too hard, the compass needle point will not penetrate it, and the compass will not hold its position. If it is too soft, it will become grooved and scarred quickly. Manila paper is commonly used to cover drawing boards. There are, however, papers now on the Market with a high gloss waterproof finish on one side which will withstand many cleanings. Also some grades of linoleum have been found satisfactory.

QUIZ

1. Why is it best to keep your instruments in a case?
2. Why is a pivot joint preferable to a tongue joint on a compass or divider?
3. How are compasses and dividers tested for alignment?
4. What is usually the first indication that a ruling pen is worn and needs sharpening?

5. **What is used for sharpening the pen?**
6. **How is the pen shaped?**
7. **How are the nibs sharpened?**
8. **Why should you not stone the inside surface of the nibs?**
9. **How are proportional dividers set to a ratio?**
10. **Why are drawing board covers used?**

CHAPTER 3

PICTORIAL DRAWINGS

MULTI-VIEW VERSUS PICTORIAL DRAWINGS

Multi-view orthographic projection is used to describe accurately objects which are to be constructed or produced. However, in order to visualize an object drawn by this method, a man must have a trained imagination. Pictorial drawing may be used instead of orthographic projection when those who are to use the drawing do not have the required training needed to read orthographic projection, or when it is desirable that the entire object be shown in a single view. In the Navy, piping diagrams, electrical wiring diagrams, and assembly drawings are often made as pictorial drawings.

The most truly pictorial method is perspective drawing. By this method, objects are made to appear proportionately smaller with distance just as they do when you look at them. (See fig. 3–1.) However, perspective drawings are difficult to make and, since lines on perspective drawings are not drawn in proportion to the edges represented, a perspective drawing cannot be used when an object is to be constructed. It is of value chiefly for illustrative purposes.

The following three methods of pictorial drawing are used in mechanical, structural, and electrical drafting:

Isometric drawing.—In an isometric drawing, the object is drawn as if it were at an angle to the picture plane, but the isometric lines are drawn in true proportion to the equivalent lines on the object. The view of the object is con-

Figure 3–1.—Perspective drawing.

structed around three axes which are 120° apart. (See fig. 3–2.)

OBLIQUE DRAWING.—In an oblique drawing, the front face of the object is shown in its true size and shape as if it were an orthographic view, and the receding lines of the other two faces shown are usually drawn at an angle of 30°, 45°, or 60° with the horizontal. These receding lines may be drawn to the same scales as the lines of the front face or to a smaller scale. (See fig. 3–3.)

CABINET DRAWING.—In a cabinet drawing, the front view is shown in its true size and shape, but the receding lines are

drawn to ½ the scale of the front view. A cabinet drawing is actually an oblique drawing which has been given a special name because it is often used for drawings of cabinet work. (See fig. 3–4.)

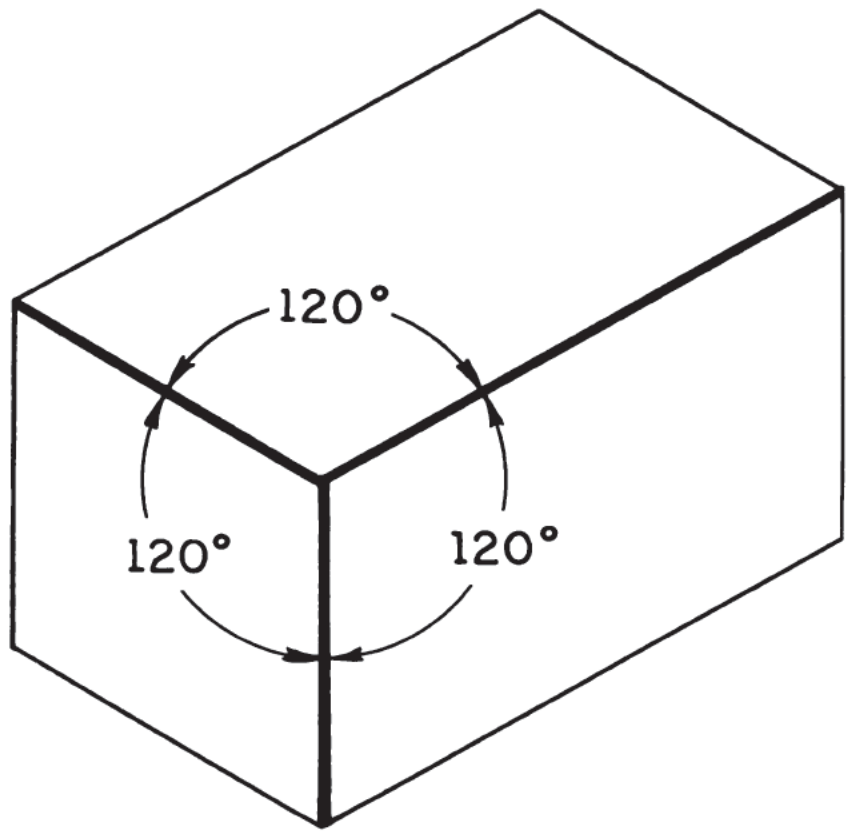


Figure 3–2.—Isometric drawing.

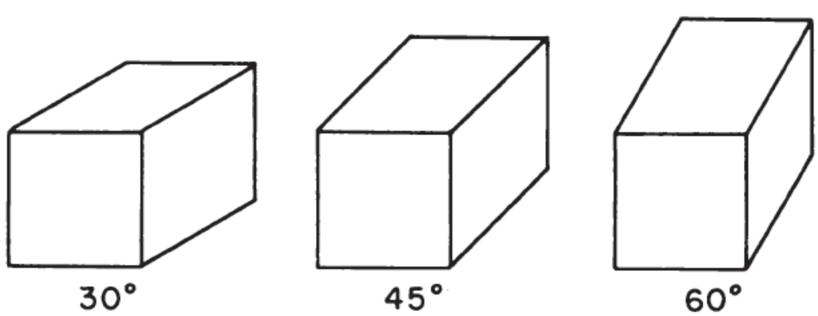


Figure 3–3.—Oblique views of a brick.

Isometric, oblique, and cabinet drawings which have long receding lines will appear as if these lines are diverging. In other words, the far end of the object will look larger than the front end. This is because the eye has been trained to the

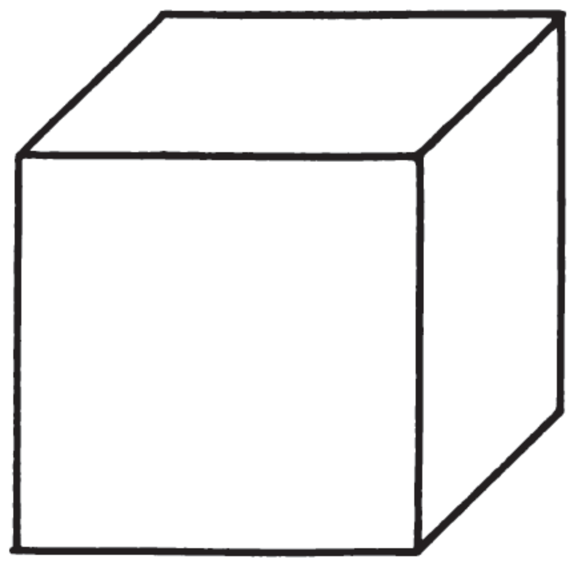


Figure 3–4.—A cabinet drawing of a cube.

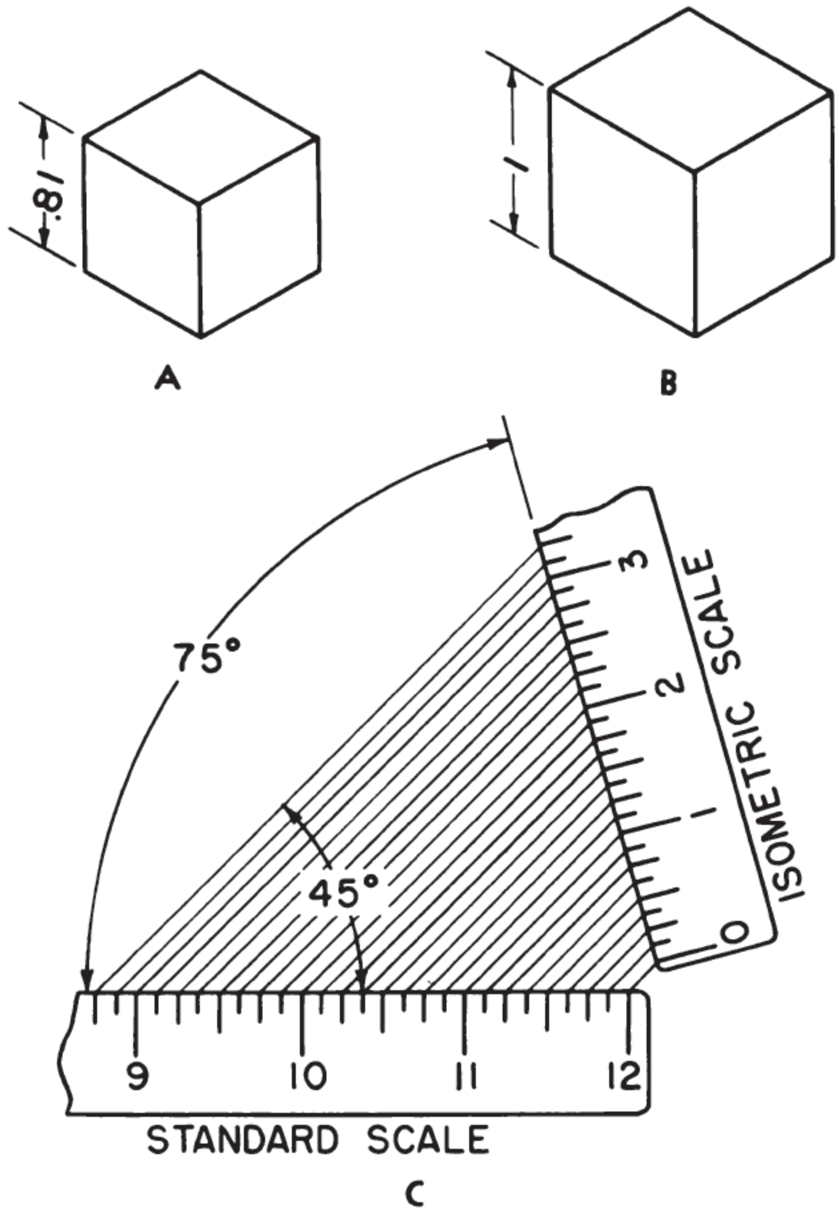
natural law of perspective in which receding lines converge or draw together. This illusion of divergence can be partly overcome by drawing the receding lines to a shorter scale, as is done in cabinet drawing.

ISOMETRIC DRAWINGS

Theoretically, isometric projection may be derived from orthographic projection with the object revolved so that three faces show on a single plane and with all edges equally foreshortened. The term isometric means equal measure. In practice, it is simpler to make isometric drawings than isometric projections. On isometric drawings all measurements are made to full scale rather than to the foreshortened isometric scale. (See fig. 3–5.)

With both the projection and the drawing, the same terms for elements are used. The edges of the object which are

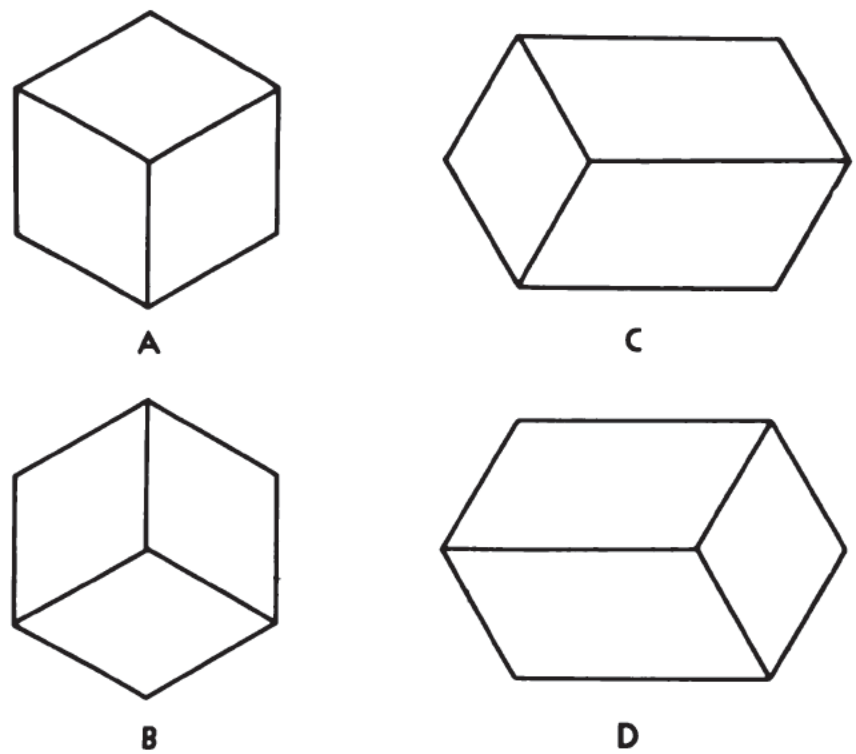
shown as 120° apart are called the ISOMETRIC AXES, and the three faces shown are called the ISOMETRIC PLANES. A line parallel to one of the isometric axes is called an ISOMETRIC LINE, and a line which is not parallel to any of the isometric axes is called a NON-ISOMETRIC LINE. All isometric lines are drawn to scale, while non-isometric lines are not.



Courtesy Delmar Publishers Inc.

Figure 3–5.—A. Isometric projection. B. Isometric drawing. C. Isometric scale derived from full scale.

Before you start an isometric drawing, it may help you to make a rough sketch of the object to determine which surfaces should be shown, as well as the best position for the isometric axes. Figure 3–6 shows the four isometric positions. Those shown at C and D are best for objects with long lines, since



Courtesy Delmar Publishers Inc.

Figure 3–6.—Four positions for the isometric axes.

when the long axis is parallel to the picture plane the unpleasant effects of divergence are avoided.

When an isometric drawing is to be made, first visualize the object as enclosed in a box. You can draw the edges of the box on the orthographic views of the object. Make the measurements for the length, width, and height of the box on the three isometric axes, as shown in figure 3–7A. Then draw the object inside the box, making all measurements on isometric lines, that is, lines parallel to the three isometric axes. Invisible edges are usually omitted.

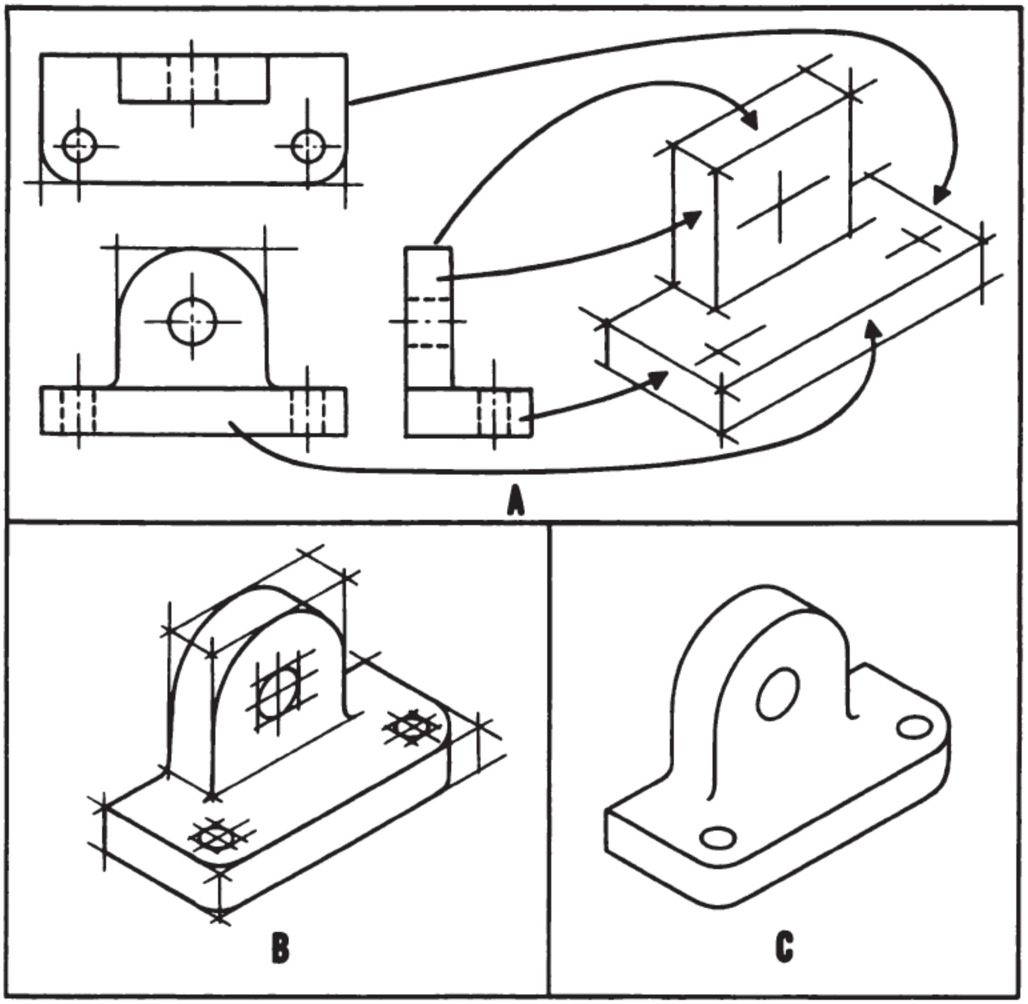


Figure 3–7.—Steps in making an isometric drawing of an object.

Now suppose you have an object on which some of the edges will not be parallel on the drawing to any of the isometric axes. These edges will be drawn as non-isometric lines. Such lines are not shown in their proportionate lengths, which means that their measurements cannot be transferred directly from an object or an orthographic view to an isometric drawing. The letter V in figure 3–8, for example, contains four of these non-isometric lines. In order to draw the V, first enclose it in a box. Then locate the end points of the non-isometric lines on isometric lines and connect these end points with lines, as shown in figure 3–8.

When the end points of non-isometric lines do not fall on

isometric lines or planes, they may be located by the co-ORDINATE CONSTRUCTION METHOD. First, enclose the orthographic views of the object in a box. Then project the ends of the sloping lines to one side of this box, as shown in figure 3–9. Next draw horizontal and vertical lines to the edges

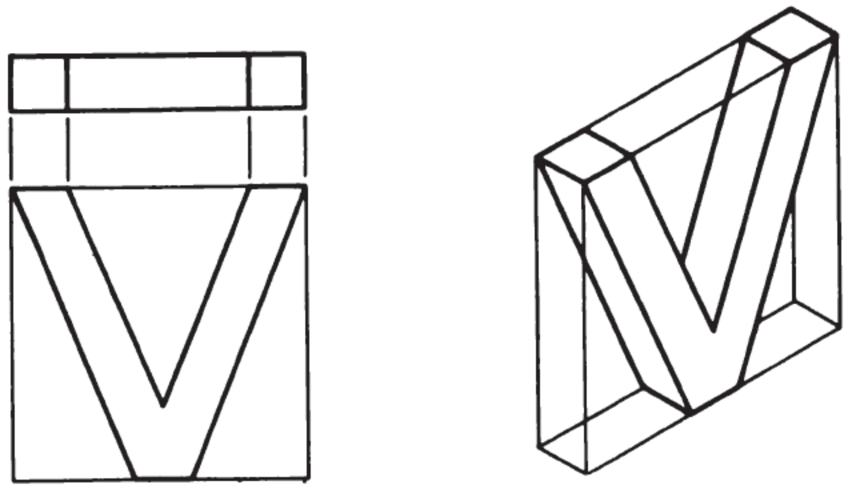


Figure 3–8.—Drawing non-isometric lines by locating the end points.

of the box, as shown in figure 3–9. Finally, draw the box with these co-ordinate lines in the isometric. Since the co-ordinate lines are isometric lines, their measurements can be transferred to the isometric view.

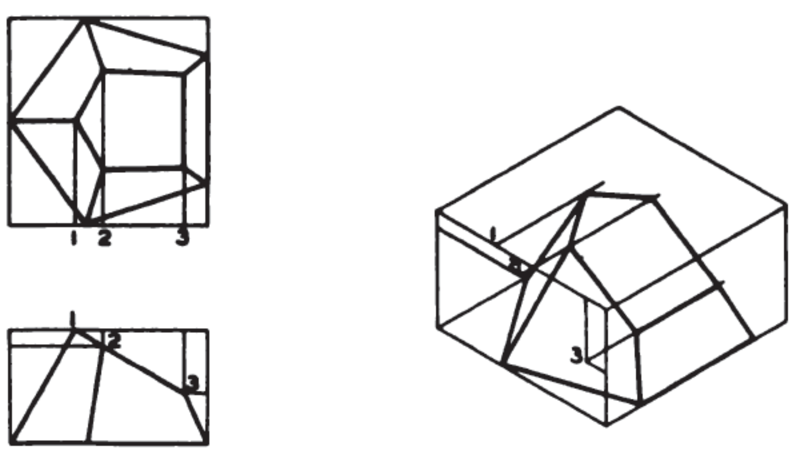


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Figure 3–9.—Coordinate construction method of drawing non-isometric lines.

When an object contains curved lines, co-ordinate lines may be used to plot these curves. (See fig. 3–10.) Draw lines from selected points along the curve in the orthographic view to the line representing the side of the box. Then transfer the measurements to the isometric drawing.

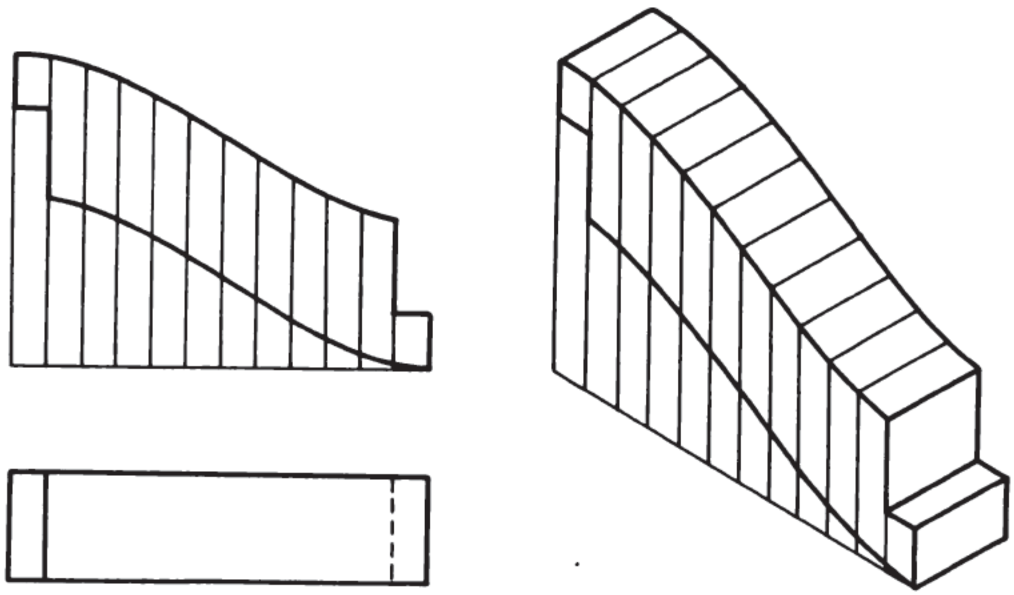

Figure 3–10.—Drawing curved lines in isometric.

Isometric circles may be plotted by the co-ordinate method, or they may be drawn as ellipses since a circle appears in the isometric as an ellipse. The four-center method is generally used to draw ellipses in isometric drawings. First, enclose the circle in the orthographic view in a square. Draw the square as a parallelogram in the isometric. Then draw two lines from the vertex of each of the obtuse angles as shown in figure 3–11A. The two lines form an angle of 60°. Each is 30° from a side of the parallelogram, and each bisects and is perpendicular to a side of the parallelogram. Use the intersections of these perpendiculars as centers from which to draw with a compass the small arcs forming the ends of the ellipse. Use the vertex of the obtuse angles as centers from which to draw the large arcs forming the sides of the ellipse.

Arcs, since they are parts of circles, are drawn in isometric

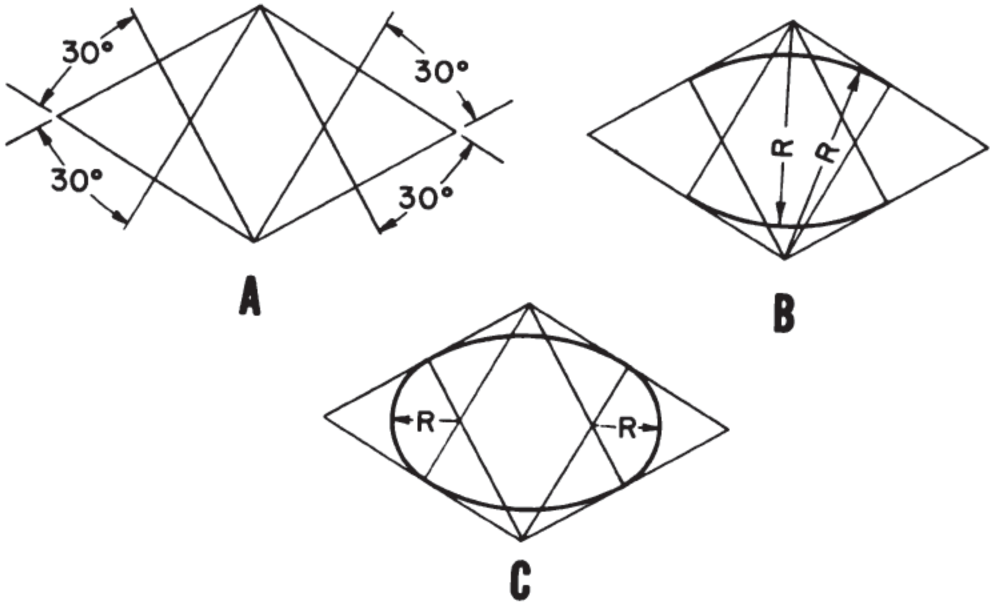

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Figure 3–11.—Drawing an ellipse wtih the four-center method.

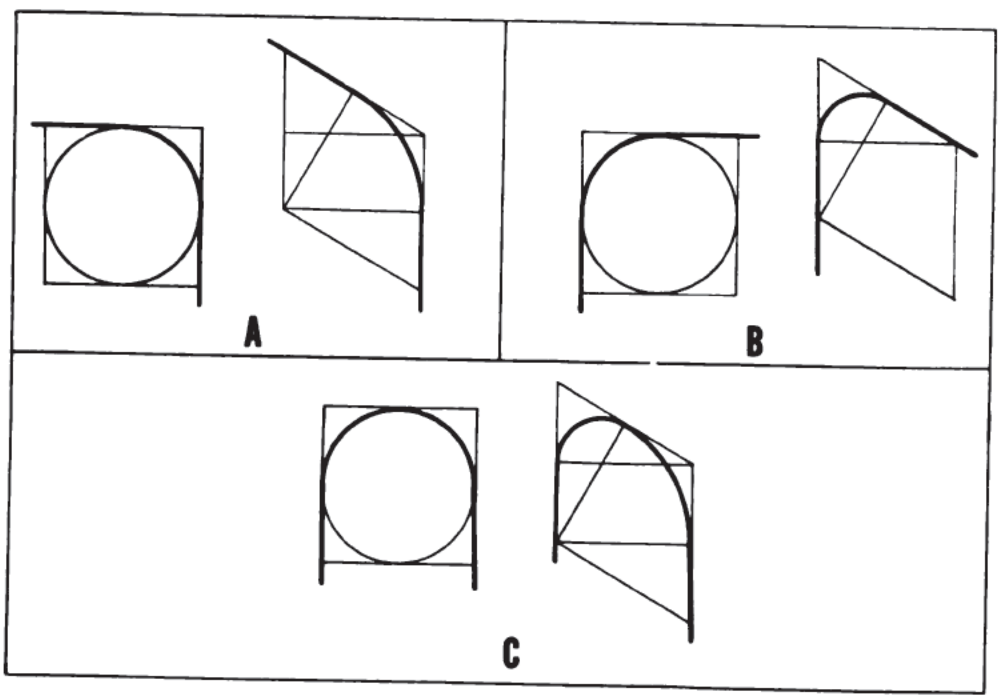

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Figure 3–12.—Drawing arcs in isometric.

as circles are drawn. Complete the arc in the orthographic view as a circle. Enclose the circle in a square. Then draw the square in isometric and locate the centers as previously described. Often it is necessary to locate only one center in order to draw the arc. (See fig. 3–12.)

Isometric Sectional Views

Sometimes, in order to show the inner structure of an object, an isometric sectional view must be drawn. The cutting plane for an isometric section should always be an isometric plane or a plane parallel to an isometric plane so

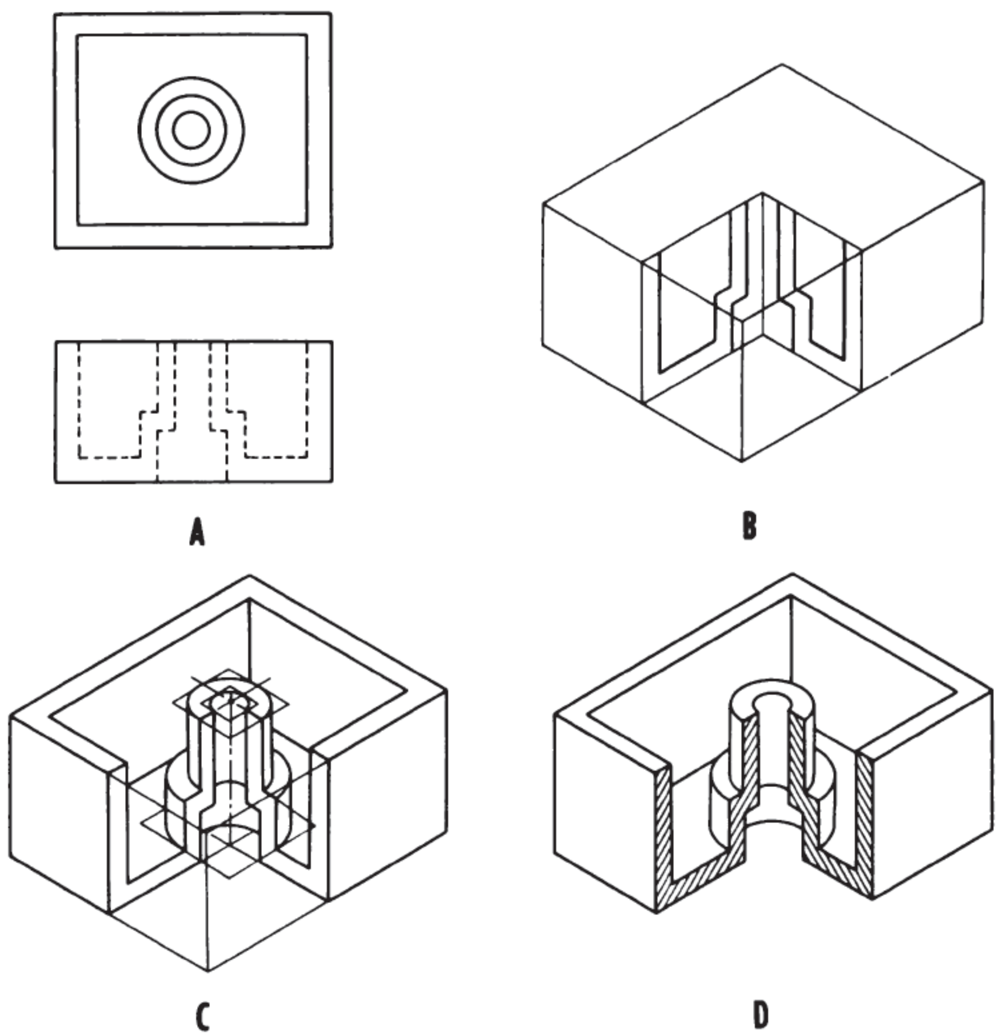


Figure 3–13.—Steps in drawing an isometric sectional view.

that the measurements may be shown. When you draw an isometric section, draw the section in contact with the cutting plane before you draw the details behind the cutting plane. (See fig. 3–13.)

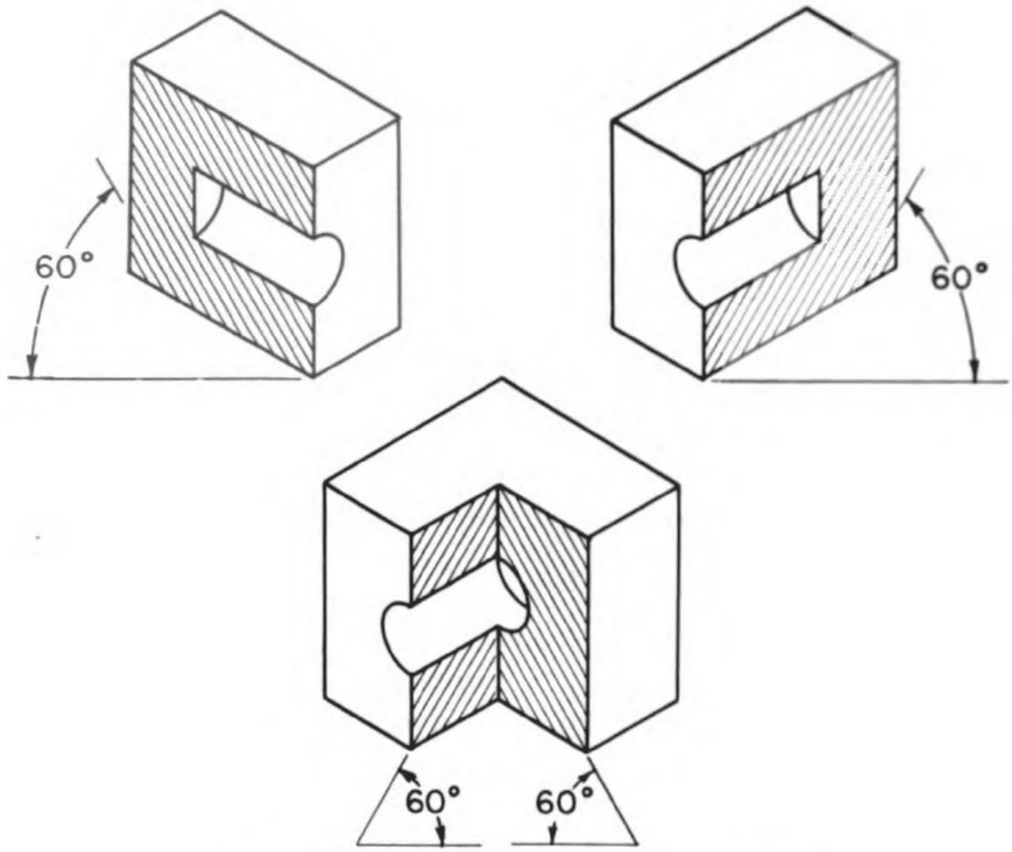


Figure 3–14.—Section lining in isometric views.

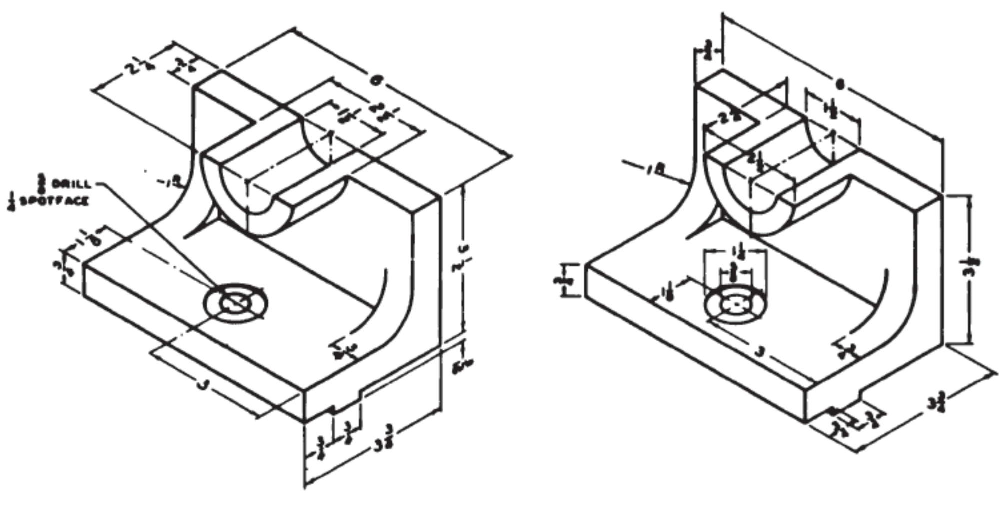
Section lining should be drawn at an angle of 60° to the horizontal in either direction in isometric sectional views. Where two parts touch each other, both of which are section lined, the lines of one part should be drawn inclined to the right and those of the other inclined to the left. (See fig. 3–14.)

Dimensioning Isometric Drawings

When you dimension isometric drawings, follow these rules:

1. Dimension visible surfaces.

2. Draw extension and dimension lines in the same isometric plane with the surfaces containing the dimensions or in an isometric plane perpendicular to these surfaces.
3. Draw dimension figures and letters in isometric. (Figures and letters in notes need not be drawn in isometric.)
4. Draw dimension lines and figures outside the outline of the object wherever possible.
5. Dimension holes with a note in which the size of the hole and the machining operation are stated.



A B

Courtesy Delmar Publishers, Inc.

Figure 3–15.—A. Isometric drawing dimensioned correctly. B. Same drawing dimensioned incorrectly.

The correct application of the rules is shown in the isometric drawing in figure 3–15A. Figure 3–15B shows incorrect dimensioning on an isometric drawing. Notice how cluttered the incorrect dimensioning appears.

OBLIQUE DRAWINGS

In oblique drawings, the front face of the object is drawn as if it were an orthographic view. It is parallel to the viewing plane and undistorted. A comparison of an oblique

projection and an orthographic projection of a cube is shown in figure 3–16.

An oblique drawing like an isometric drawing has three axes. One is always parallel to the horizontal; one is always

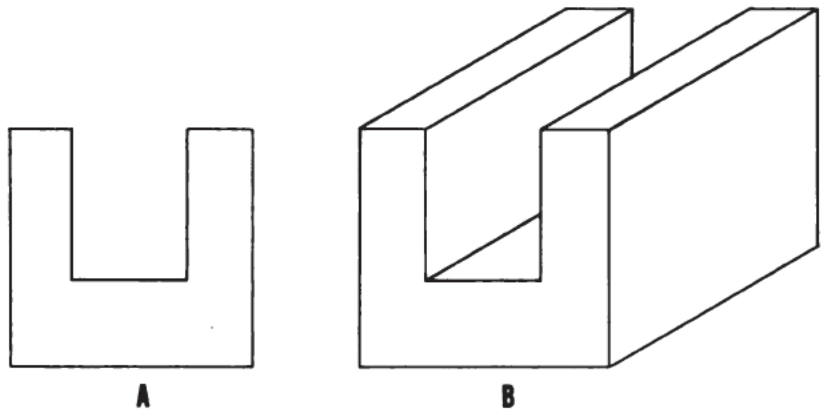


Figure 3–16.—A. Orthographic view of the front of an object. B. Oblique view of the object.

perpendicular to the horizontal; and the other is at any angle other than 90° to the horizontal. Figure 3–17 shows some of the various angles possible.

When an oblique drawing is made with the receding axis at an angle of 45° and the receding lines are drawn to full scale the projection is called a CAVALIER PROJECTION. An oblique drawing in which the receding lines are drawn to ½ scale is called a CABINET DRAWING. (See fig. 3–18.)

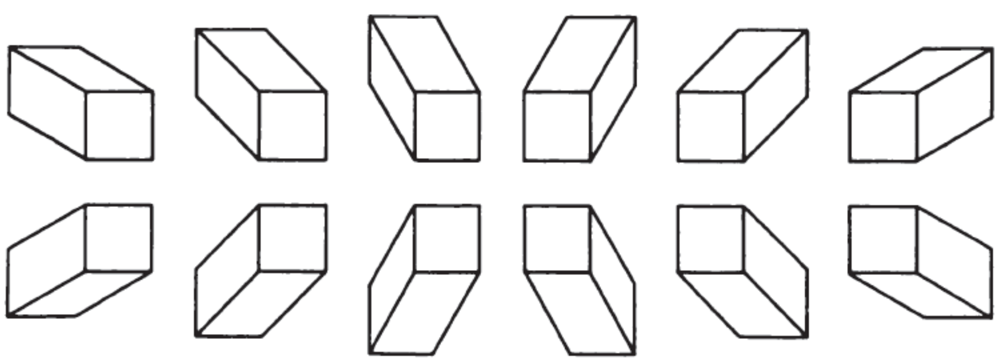


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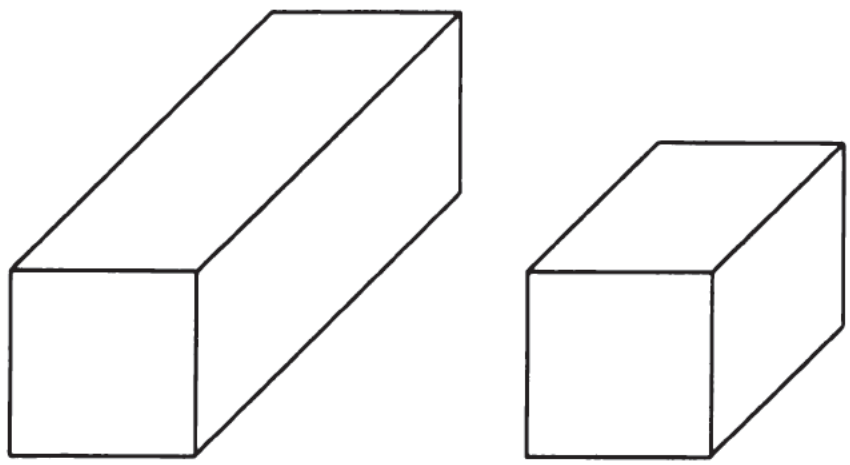
Figure 3–17.—Various angles of the receding axis.

Like isometric drawings, oblique drawings are made by first enclosing the object in a box. (See fig. 3–19.) Measurements are made on the oblique axes or lines parallel to them. The end points of inclined lines are located on oblique lines and then the end points are joined with lines. Curved lines or circles may be plotted by the co-ordinate method. Circles appear as ellipses on the receding sides in oblique



A B

Figure 3–18.—A. Cavalier drawing. B. Cabinet drawing.

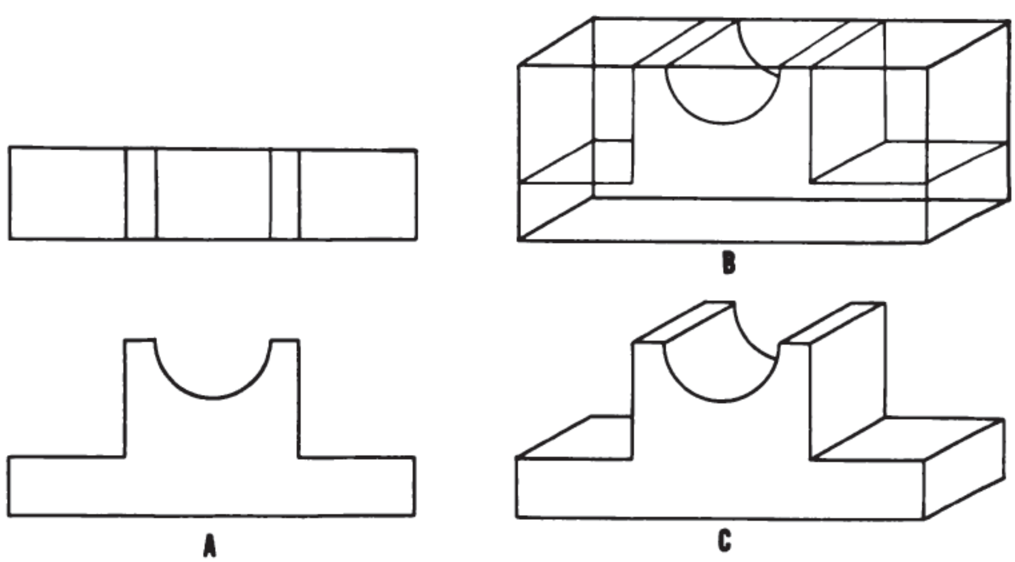


Figure 3–19.—Steps in making an oblique drawing.

drawings, and the four-point method may be used to draw them. However, ellipses in oblique drawings often appear distorted. For this reason, DRAW THE FACE OF THE OBJECT WHICH SHOWS A CIRCULAR OR AN IRREGULAR OUTLINE AS THE FRONT FACE, PARALLEL TO THE PICTURE PLANE. (See fig. 3–20.)

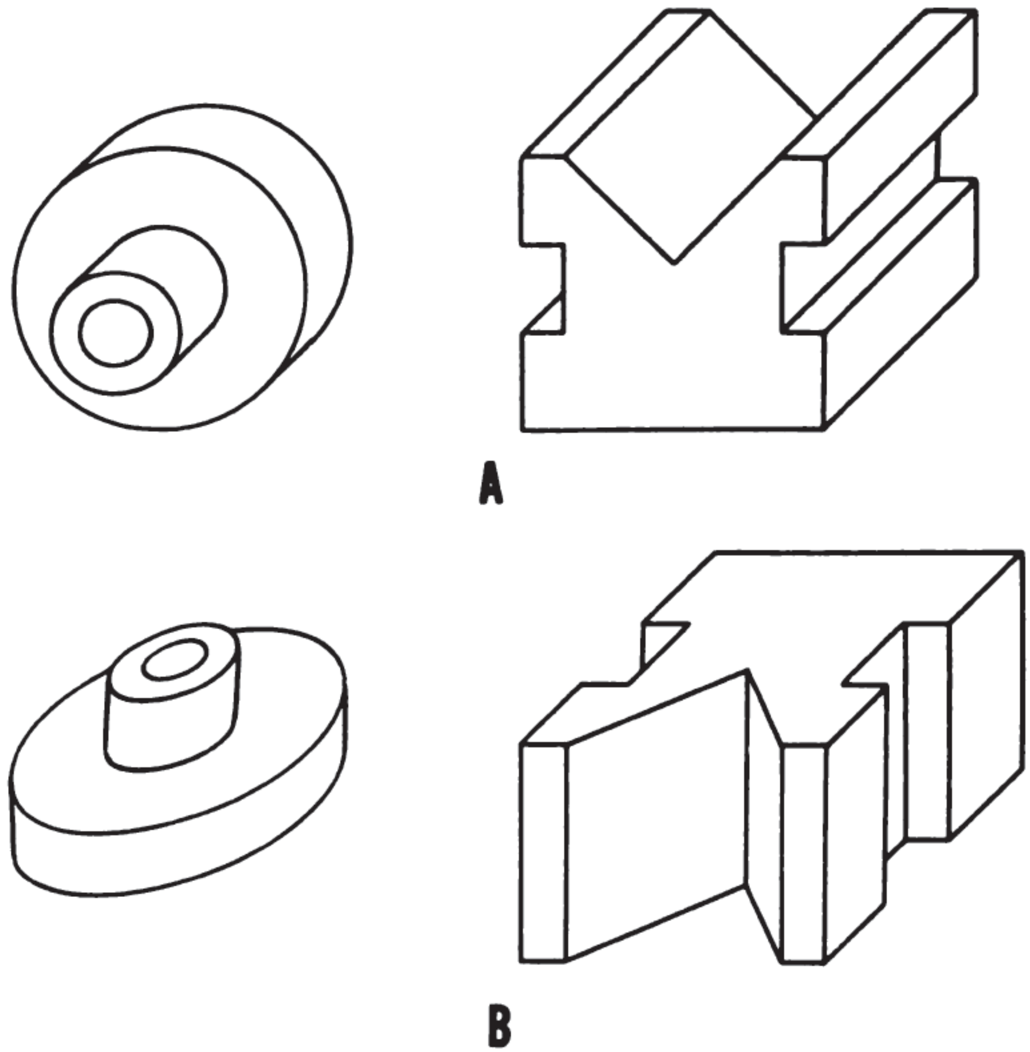


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Figure 3–20.—A. Right: contour parallel to picture plane. B. Wrong.

Oblique drawings, like isometric drawings, appear distorted because the receding lines are drawn parallel to each other, rather than converging. For this reason, DRAW AN OBJECT WITH ITS LONGEST AXIS PARALLEL TO THE PICTURE FRAME,

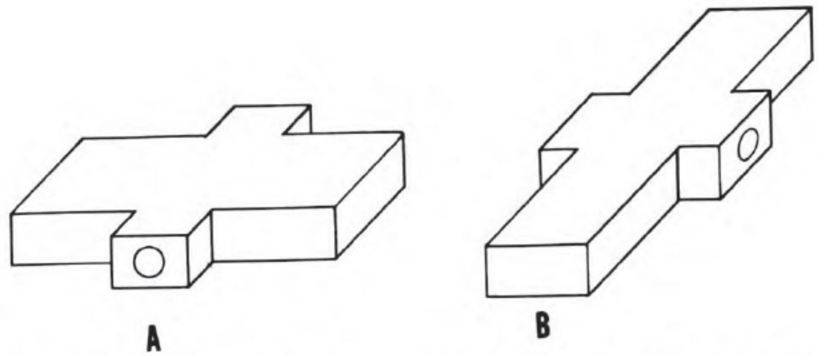


Figure 3–21.—A. Right: longest axis parallel to the picture plane. B. Wrong.

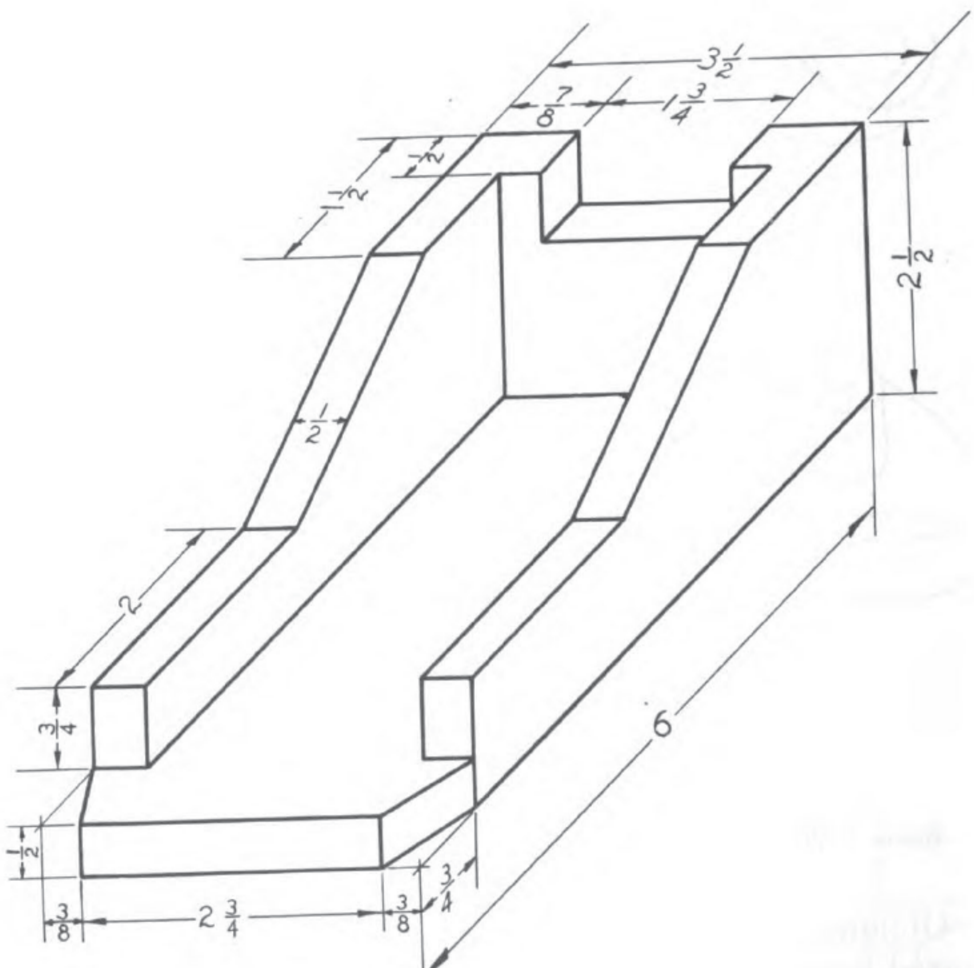


Figure 3–22.—Oblique drawing dimensioned correctly.

as shown in figure 3–21. However, when one plane shows a circle or irregular outline but is not on the long axis, it should be drawn as a front face in preference to other planes without circles or irregular outlines. When an object has two circular faces, draw the one with the longest axis parallel to the picture plane.

Oblique drawings are dimensioned like isometric drawings. Figure 3–22 shows an oblique drawing dimensioned correctly.

PICTORIAL SKETCHING

Techniques for making working sketches in orthographic projection are discussed in chapter 7, *Draftsman 3*, NavPers 10471. It may be helpful to review some of the basic techniques of sketching in this section.

Use a fairly soft pencil, and in order to control your lines, draw them with a series of short strokes. Block in the object first with light lines. Then draw the major outlines of the object lightly. Finally, draw the details of the object. You can darken, or brighten, the lines when you are sure they are right, and then erase light construction lines and lines which are incorrect.

It is not necessary for a man to have artistic ability in order to make good sketches. The ability to make pictorial sketches is particularly useful. You may find that you will have occasion to draw pictorial sketches more often than to make finished pictorial drawings. In designing and inventing, engineers often draw pictorial sketches first. You may be asked to work from such a sketch to make a finished drawing. You may make a sketch yourself before you begin a drawing in order to better visualize the object, or you may find it helpful to make a sketch in order to help someone else read a drawing.

Isometric Sketches

Since isometric sketches are not expected to be as accurate as isometric drawings, you can foreshorten the receding edges to avoid the appearance of distortion, or you may even make

the lines converging. When you make an isometric sketch, first establish the lines of axes. Then, as with isometric drawings, block in the object with box-like forms in the isometric. (See fig. 3–23.) Finish by drawing the outlines of the object and adding the details.

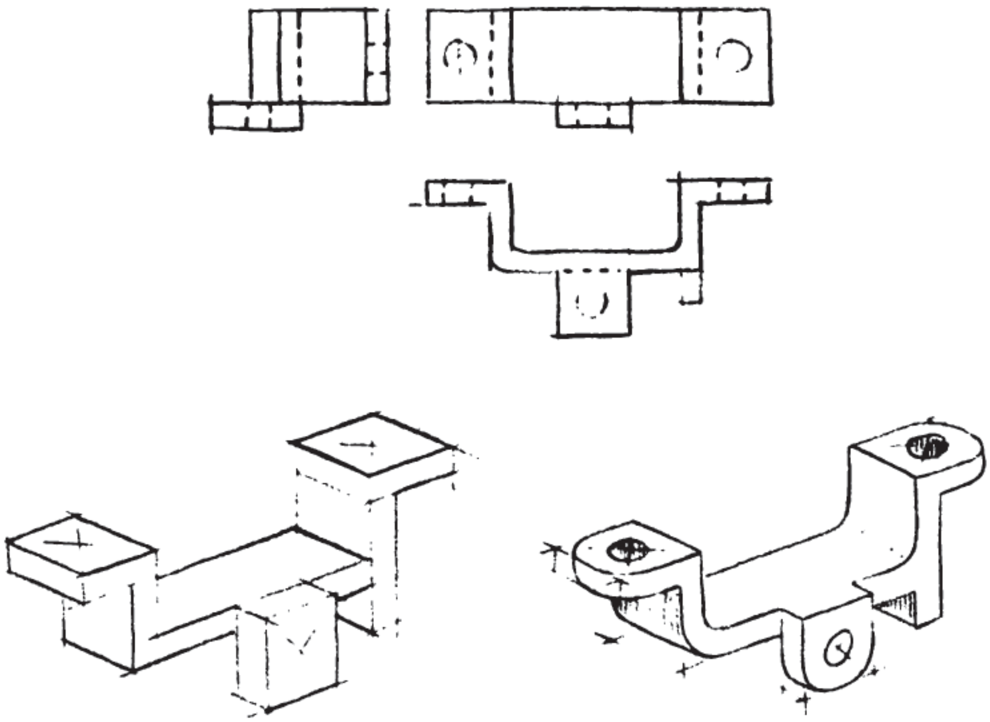


Figure 3–23.—Steps in making an isometric sketch.

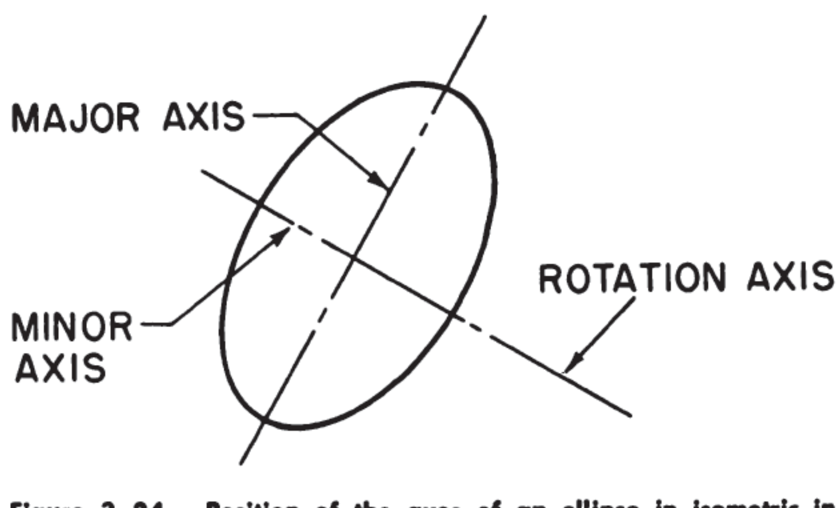


Figure 3–24.—Position of the axes of an ellipse in isometric in relation to its rotation axis.

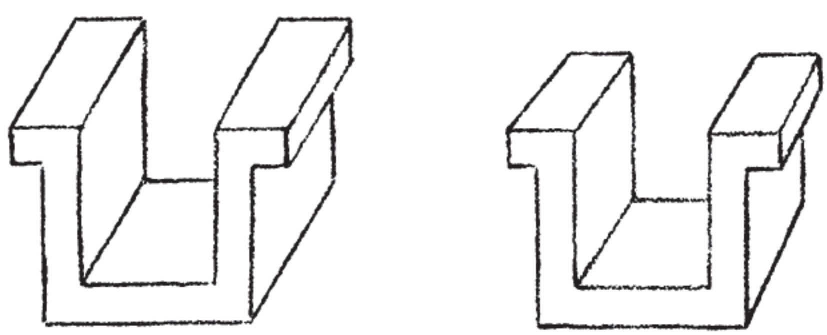
It is important to remember that circles appear in the isometric as ellipses and that the major axis of the ellipse is always at right angles to the shaft or rotation axis. Thus, the minor axis coincides with the shaft or rotation axis. (See fig. 3–24.)

In dimensioning isometric sketches, follow the general rules given in the section on isometric drawing. Be sure to keep the extension lines either in the same plane with the features to be dimensioned or perpendicular to them.

Cross-section paper can be obtained with isometric lines. This can be helpful when you make an isometric sketch.

Oblique Sketches

Oblique sketches, like oblique drawings, show a front face which is undistorted. The appearance of distortion can be avoided in the other faces if the receding lines are foreshortened and slightly converged. (See fig. 3–25.) This use of converging lines in either isometric or oblique sketching is sometimes called *fake perspective.*



A B

Figure 3–25.—A. Oblique sketch. B. Oblique sketch with foreshortened receding lines.

Perspective Sketches

Perspective sketches are the most effective of the pictorial sketches, and unlike perspective drawings, they are not particularly difficult to make. To make a perspective sketch, you need only observe the ordinary phenomena of nature.

Objects appear smaller in proportion to their distance from the eye and receding lines converge. Receding horizontal lines or planes which are parallel appear to converge to a vanishing point on the horizon. (See fig. 3–26.)

When you make a perspective sketch from an object, you can use a pencil to measure the relative lengths of lines and their apparent angle. Hold the pencil at arm's length between you and the object. Turn the pencil to the apparent angle of an edge; note the apparent length of the edge compared to the pencil; and then, without changing its angle, shift the pencil to the paper and mark the beginning and end of the line with another pencil. This method of estimating angles and measuring will be most successful if you position your paper so that it is perpendicular to your line of sight to the object.

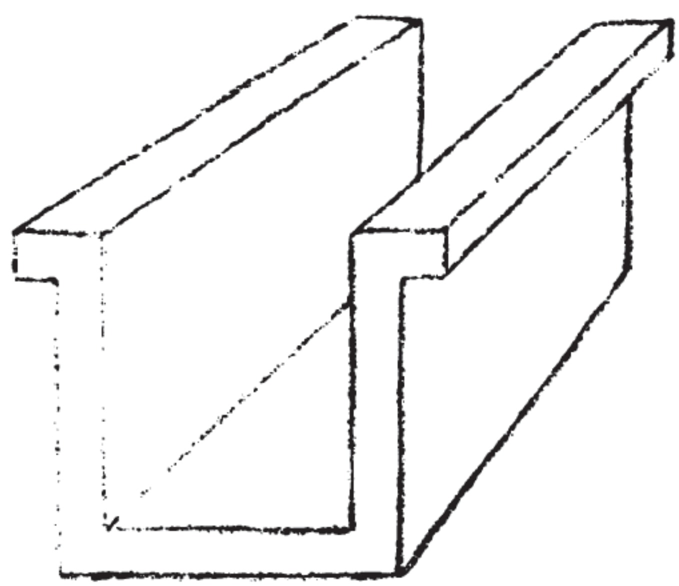


Figure 3–26.—Perspective sketch.

If you find that you have a tendency to make the sketch too small, try blocking it in very roughly first with light lines. Then, using the pencil to estimate angles, sketch the principal lines, running them past the lines of the figure toward their vanishing points. Block in circles with squares and arcs with angles or rectangles. (See fig. 3–27.)

SHADING

Shading is sometimes an aid in clarifying pictorial drawings, sketches, and orthographic views, as well as improving their appearance. On orthographic views, its use will sometimes bring out details which are difficult to show otherwise and thus eliminate the need for an additional view. In some

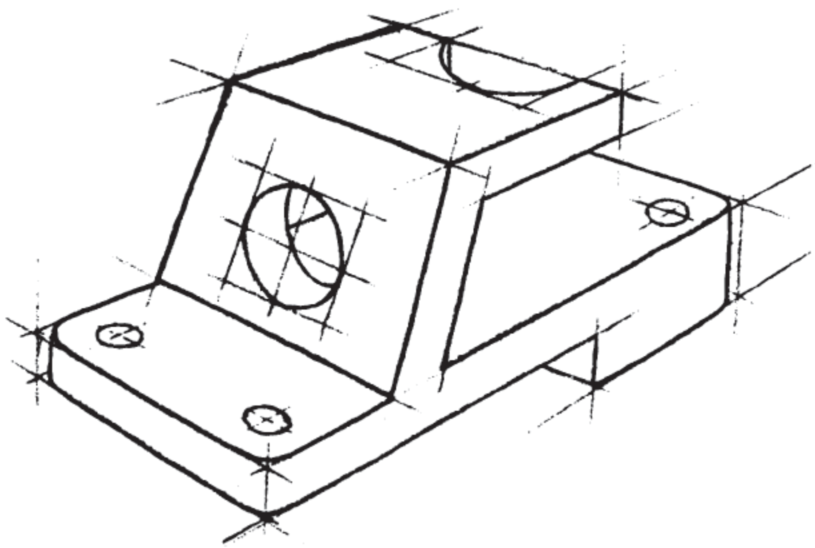


Figure 3–27.—Perspective sketch with the object set at an angle.

views, shading helps prevent an optical illusion, for example, when a surface which projects on the object appears to recede in the drawing. On patent drawings, shading is required. However, on mechanical working drawings, shading is rarely used because it requires extra time and sometimes can be very misleading, rather than helpful. It is unlikely that you will be required to do shading very often in the Navy. For this reason, the following discussion of shading techniques is very brief.

Shade Lines

On outline drawings, the lines may be drawn as if one side were in shade and one in light. In this method of indicating shade, the source of light is assumed to be at an angle of 45° to the horizontal from the left and top of the drawing. The lines which define the light side are drawn as fine lines, and those on the dark side are drawn about three times as

wide. Hidden lines should never be shaded. (See fig. 3–28.)

Round objects present a special problem with this type of shading. There are two methods for drawing the heavier shade line on one side of a circle. In one method, the center is shifted, as shown in figure 3–29A. First, the circle is drawn with the compass. Then the center is shifted on a line from the source of light. Finally, a semicircular arc is drawn with the compass on the dark side of the circle.

The second method is more difficult and is used only by skilled draftsmen, although it is faster than shifting the

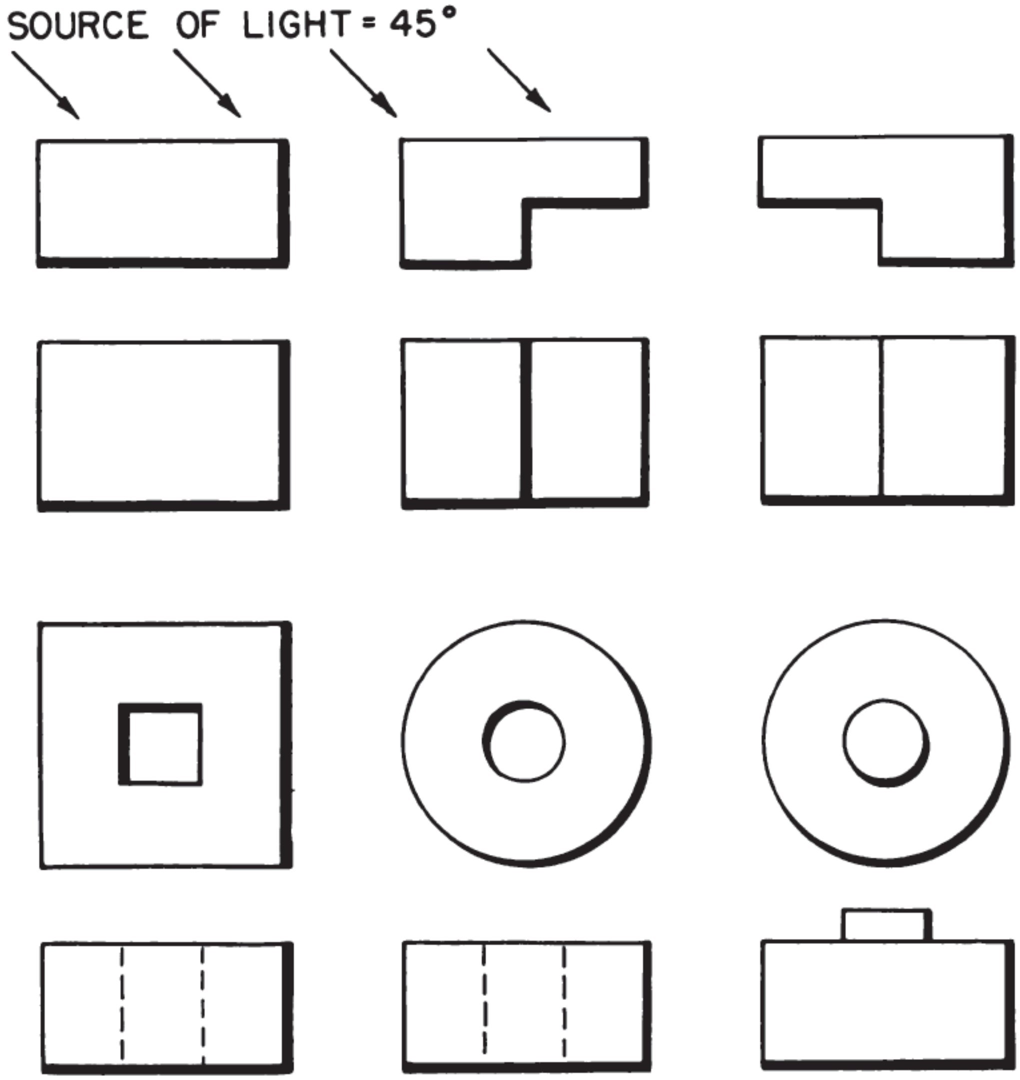


Figure 3–28.—Examples of the use of shade lines.

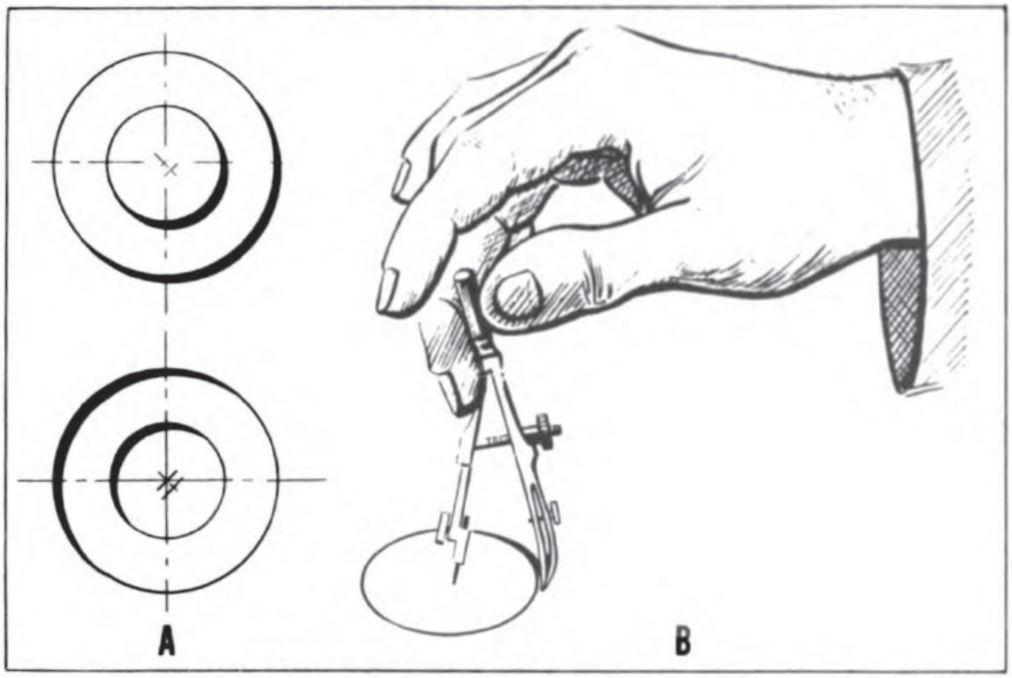


Figure 3–29.—A. Shifting the center of the circle. B. Springing the legs of the compass.

center. First, the circle is drawn with the compass. Then, using the same center, the draftsman gradually springs the legs of the compass and brings them back again as he draws the semicircle, so that the shading is produced in a smooth line. (See fig. 3–29B.)

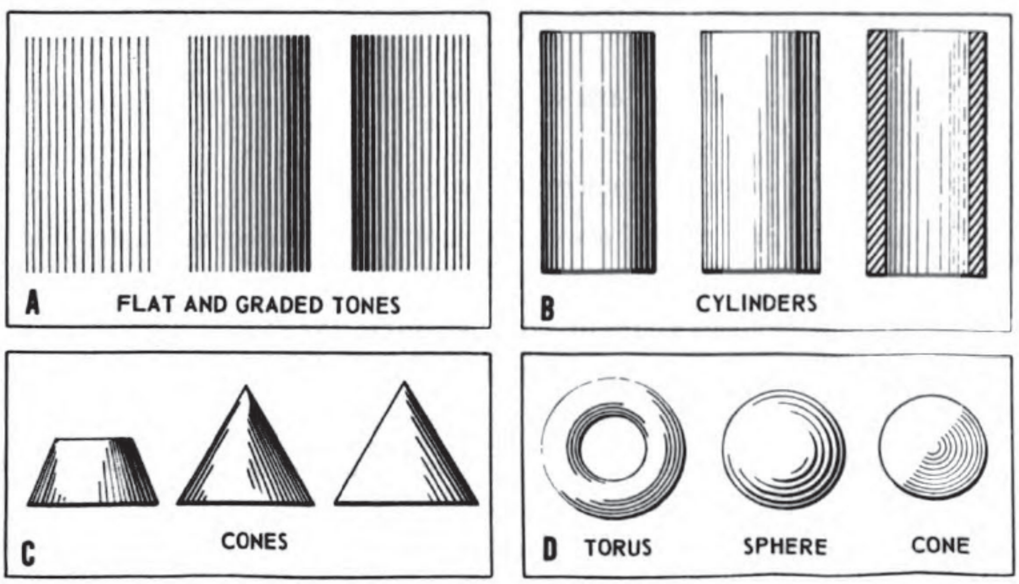


Figure 3–30.—Line shading.

Line Shading

In line shading, the effect of shade is achieved by means of ruled lines. The light is usually considered to come from the front and slightly to the left. Flat surfaces are represented by flat tints, composed of lines of equal widths. Curved or inclined surfaces with graded tints are represented by lines of graduated weight. (See fig. 3–30.)

For example, on a vertical cylinder, the brightest surface is slightly to the left of the middle and the darkest portion lies not at the right side but between it and the edge of the light. For a brief explanation of this phenomena, read chapter 14, *Draftsman 3*, NavPers 10471.

Tone Shading

Tone shading is occasionally of value, especially in perspective sketches and illustrations. As in line shading, a source of light should be established and the tones used to express form or texture. A discussion of the use of tone to show form and of various materials and techniques used in making drawings with line or tone shading is included in chapter 14 of *Draftsman 3*.

QUIZ

1. Why can't perspective drawings be used when an object is to be constructed?
2. What does the term isometric mean?
3. What is the difference between isometric projection and isometric drawing?
4. How many degrees apart are the isometric axes?
5. What is a line which is parallel to one of the isometric axes called? One which is not parallel?
6. Why is it best that the long axis in an isometric drawing be parallel to the picture plane?
7. When the end points of non-isometric lines do not fall on isometric lines or planes, how are they located?

8. What two methods may be used to draw circles as ellipses in the isometric?
9. The cutting plane is always what kind of a plane in an isometric sectional view?
10. In what relation to the surfaces dimensioned should extension and dimension lines be drawn on isometric drawings?
11. How is the front face of an object drawn in oblique drawings?
12. At what angle is the receding axis of an oblique drawing?
13. What is an oblique drawing called in which the receding lines are drawn to ½ scale?
14. Why should the face of the object which shows a circular or irregular outline be drawn as the front face in oblique drawings?
15. Why should an object be drawn with its longest axis parallel to the picture frame, provided the other faces shown do not have circular or irregular outlines?
16. What is the relation between the shaft or rotation axis of an ellipse in an isometric sketch and the major axis of the ellipse?
17. What phenomena of nature do you need to observe when you make a perspective sketch?
18. At what angle to the horizontal is the source of light generally assumed to be in outline drawings where shade lines are used?
19. What are the two methods for drawing shade lines on circles?

CHAPTER 4

MATHEMATICS

INTRODUCTION

Unless you have a firm grasp of the basic operations of arithmetic, you cannot expect to be able to use mathematics successfully. If you can use numbers accurately and easily, you will find that mathematics is less difficult than you may have been led to suppose.

Mathematics is, as a matter of fact, very much like mechanical drawing in that, once you have a grasp of the principles, it becomes a matter of skill which can be acquired by practice. If you have never had occasion to use algebra, geometry, trigonometry, or logarithms, or have not had the occasion for some time, you will need to practice in order to develop the necessary skill. When you are using these tools steadily on the job, you will find that their use becomes almost second nature to you, so that problems which would otherwise be extremely complex can be solved quickly with a minimum of effort.

The Navy has prepared two basic Navy Training Courses on Mathematics. They are *Mathematics*, Volume 1, NavPers 10069–A and *Mathematics*, Volume 2, 10070–A. In these two texts, all the mathematics required in the qualifications for advancement to DM2 are discussed. In *Mathematics*, Volume 1, simple problems in plane geometry are presented in chapters 6, 7, 8, and 10, and the extraction of roots in chapter 11. In *Mathematics*, Volume 2, areas and volumes are discussed in chapter 3, the essentials of trigonometry in chapter 5, and the raising of numbers to powers and logarithms in chapter 9.

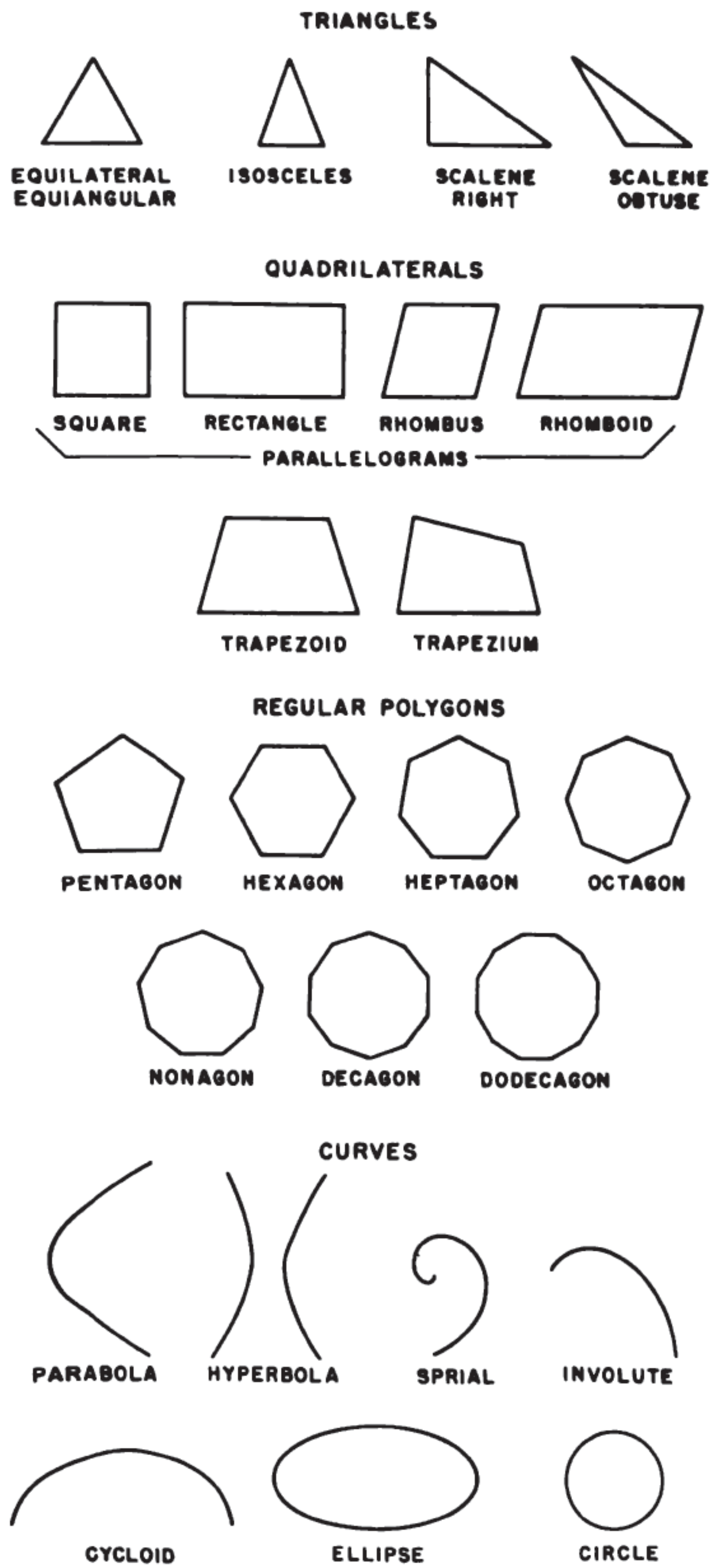


Figure 4–1.—Common plane figures.

However, it will probably pay you to look at the other chapters in the two courses in order to see in what basic mathematical operations you may be weak. This is made easy for you by the general scheme of each chapter. A review test is presented before each section on a single process. If you pass the test, you may skip the pages that teach you the ideas involved in the test. If you fail the test, study the pages that teach the mathematics involved, and then try the test again.

PLANE GEOMETRY

In your work, you use plane geometry constantly. As a Draftsman 3, you have become familiar with many geometrical solutions. This section is designed to provide a review of some of the most useful postulates of plane geometry. Figure 4–1 shows common plane figures.

An angle is the space between two intersecting straight lines. An angle is defined more precisely in mathematics as a measure of the amount of turning necessary to bring one line or plane into coincidence with or parallel to another. It is usually measured in degrees of arc, 1 degree equalling $\frac{1}{360}$ of a revolution, or circle. In mathematical computations, angles are often measured in radians, an angle of 1 radian having an arc equal to its radius. There are 2 pi radians to a revolution or circle.

The following review test on angles appears at the beginning of chapter 6 of *Mathematics*, Volume 1, NavPers 10069–A.

Part I. (*Time: 3 minutes*)

1. Copy and complete:

(a) An angle is an amount of .... of a line in a plane about a fixed point, called the ....

(b) In speaking of the angle shown in figure 4–2, one can refer to it in three ways: (1) as angle ...., or (2) as angle ...., or (3) as angle ....

(c) "I estimate that the angle shown here is about .... degrees."

(d) In navigation an angle is measured clockwise from ....

(e) Thirty-six degrees twenty-four minutes forty-five seconds is written ....

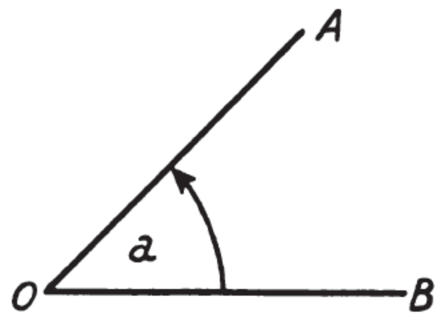


Figure 4–2.—An angle.

(f) One complete rotation equals .... degrees; a degree is divided into .... minutes; a minute is divided into .... seconds.

2. With a protractor measure the angle x shown in figure 4–3; the angle y; the angle z.

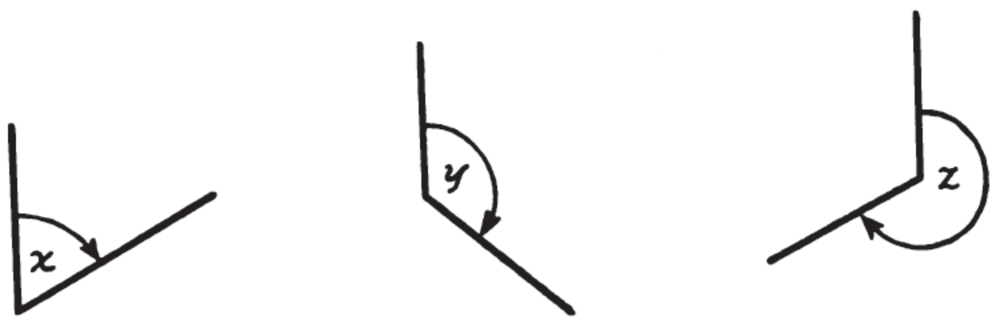


Figure 4–3.—Angles.

3. By means of a protractor, draw an angle of 54°; one of 116°; one of 241°.

4. On a 24-hour clock, 1 a. m. is called ....; 1 p. m. is ....; 11 a. m. is ....; midnight is ....

5. Using the 24-hour basis write the following:

(a) two-thirty a. m.
(b) two-thirty p. m.
(c) one-thirty a. m.
(d) one-twelve p. m.
(e) eleven-five a. m.
(f) eleven-five p. m.

6. Through how many degrees of angle will the hour hand move as it turns from 2400 to 0100? From 2400 to 0200? From 2400 to 0500? From 2400 to 0600? From 2400 to 0900?

7. Add $24°28.2'$ to $42°54.4'$.

8. Subtract $24°28.2'$ from $42°54.4'$.

9. A ship is on a course 030°; suppose it is designed to change the course 65° to the left. You would find the new course by subtracting 65° from 30°. What is the new course?

Part II. (*No time limit*)

10. Tom Blake measured the angle shown in figure 4–2 with a protractor. He said, "Angle x is 110°." What caused Tom to make his error? (It is a common fault of beginners.)

11. Very often in navigation the angles are given to the nearest tenth of a minute instead of second. Using that method, how would you write $20°42'18''$?

12. (a) Define a radian. (b) A radian is equal to about how many degrees? (c) A degree is about what part of a radian?

The answers to these problems are given in appendix I of NavPers 10069–A. If you can answer them correctly, you can safely skip the rest of chapter 6 in *Mathematics*, Volume I.

Next take test 20 on page 152 in chapter 7 and then test 21 on page 157. If you can pass these tests, you are pretty well up on the facts about angles, as well as having a grasp of some of the facts about triangles and other plane figures.

A triangle is a plane figure bounded by three straight lines. This is the smallest number of straight lines that can be used to enclose a plane figure. The triangle is one of the most important of geometric figures. Many computations on other plane figures can be accomplished by dividing them first into a system of triangles and simple parallelograms. Many of the geometrical solutions used in the drafting room are based on the properties of triangles. In structural design, a truss is defined as a system of triangles, and the majority of the computations connected with it are made on that basis.

A test for similar triangles is given on pages 189, 190, 191, and 192 of NavPers 10069–A. It is chiefly concerned with the ratios between sides and angles of similar triangles. However, the second part of the test is concerned with

axioms for solving equations. In this same way, you will find the interdependence of the various fields of mathematics treated throughout the book. If you have a grasp of the language of algebra, you can more easily solve the problems of geometry. If you understand the relationships between the parts of the geometrical figures, other areas of mathematics can be grasped more quickly. For example, in order to understand the essentials of trigonometry, you must understand the ratio between the sides and angles of similar triangles.

Many of the so-called rules of mathematics are concerned with relationships. For example, the famous rule of Pythagorus, which is discussed in chapter 11 of NavPers 10069–A, is concerned with the relationship between the three sides of a triangle. In using this rule, you may have to work with squares and square roots and with algebraic formulas.

Algebra has often been called the shorthand of mathematics. With it, we are able to put lengthy verbal statements of problems and processes into concise, understandable form, and to shorten or eliminate many arithmetical processes. All mathematics beyond arithmetic is either related to, or based on, algebra.

It is for this reason that the first 2 chapters of *Mathematics*, Volume 2, NavPers 10070–A are on algebra, and for the same reason, you should not skip these 2 chapters unless you are very sure of your ability to use algebra. Understanding of algebra is necessary in order to understand Chapter 3, Areas and Volumes. The test on page 24 in this chapter is concerned almost entirely with the use of formulas to find the area of plane figures and the volume of three-dimensional ones.

TRIGONOMETRY

Basic trigonometry is discussed in chapter 5 of NavPers 10070–A. If you can pass the test in the first part of that chapter, you have a pretty good grasp of the essentials.

What you need to remember about trigonometry is that the ratios between any 2 designated sides of a right triangle are the same as those between the same 2 sides of all similar triangles. These ratios are called the trigonometric FUNCTIONS. Tables of trigonometric functions are given in appendices III and IV of this manual.

Actually there are six of these trigonometric functions, instead of three. Three stand for ratios between two different sides of a triangle and three more stand for the reciprocals of these ratios. For example, figure 4–4 shows a right triangle with side x, y, and r and an acute angle designated by the Greek letter theta (θ).

The ratio of the side opposite θ divided by the side adjacent to θ is called the TANGENT of θ and is written TAN θ; the ratio of the side opposite θ divided by the hypotenuse is called the SINE of angle θ, written SIN θ; and the adjacent side divided by the hypotenuse is called the COSINE of angle θ, written cos θ. The other 3 functions are the reciprocals of these 3. That is, the ratios are reversed. All 6 of the functions are listed below and the reciprocals are connected on the right by solid lines.

sine of angle $\theta=\frac{\text{opposite side}}{\text{hypotenuse}}$; written $\sin\theta=\frac{y}{r}$.

cosine of angle $\theta=\frac{\text{adjacent side}}{\text{hypotenuse}}$; written $\cos\theta=\frac{x}{r}$.

tangent of angle $\theta=\frac{\text{opposite side}}{\text{adjacent side}}$; written $\tan\theta=\frac{y}{x}$.

cotangent of angle $\theta=\frac{\text{adjacent side}}{\text{opposite side}}$; written $\cot\theta=\frac{x}{y}$.

secant of angle $\theta=\frac{\text{hypotenuse}}{\text{adjacent side}}$; written $\sec\theta=\frac{r}{x}$.

cosecant of angle $\theta=\frac{\text{hypotenuse}}{\text{opposite side}}$; written $\csc\theta=\frac{r}{y}$.

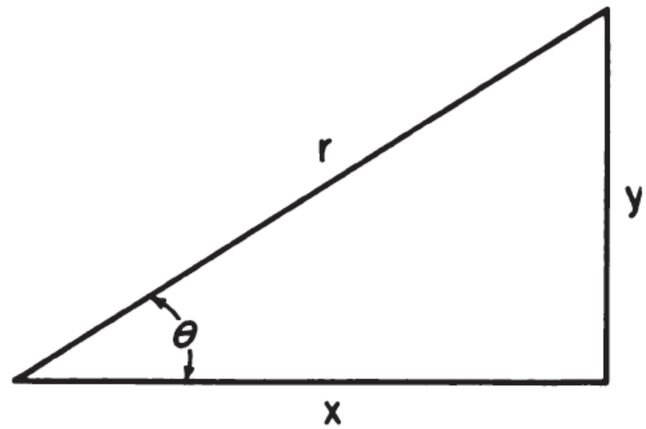


Figure 4–4.—Right triangle

The reciprocals may also be expressed in terms of each other, thus

$$\tan \theta = \frac{y}{x} = \frac{1}{\frac{x}{y}} = \frac{1}{\cot \theta}.$$

$$\sin \theta = \frac{y}{r} = \frac{1}{\frac{r}{y}} = \frac{1}{\csc \theta}.$$

$$\cos \theta = \frac{x}{r} = \frac{1}{\frac{r}{x}} = \frac{1}{\sec \theta}.$$

Most of the problems you will have to solve will be concerned with right triangles. But trigonometry can be used to solve other types of angles. Since an isosceles or an equilateral triangle is symmetrical, it is easy to solve by the same methods used to solve right triangles. For example, in figure 4–5, a perpendicular is erected from the base to the vertex of the opposite angle. This creates two right triangles. If 1 side and 1 angle of the original triangle are known, then 1 side and 2 angles of each of the 2 right triangles are known, and they may be solved for the other sides and the angle.

However, trigonometric functions may be applied to angles of any magnitude, not only to angles under 90°. In solving triangles that are not right triangles, various algebraic formulas are used. In defining the trigonometric functions of the angles, the same rectangular coordinate system is used as that discussed in connection with graphs. In figure 4–6. a

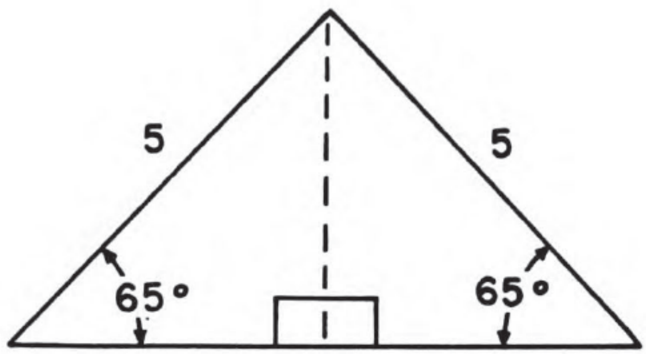


Figure 4–5.—Solving an isosceles triangle for which 1 side and 1 angle are given.

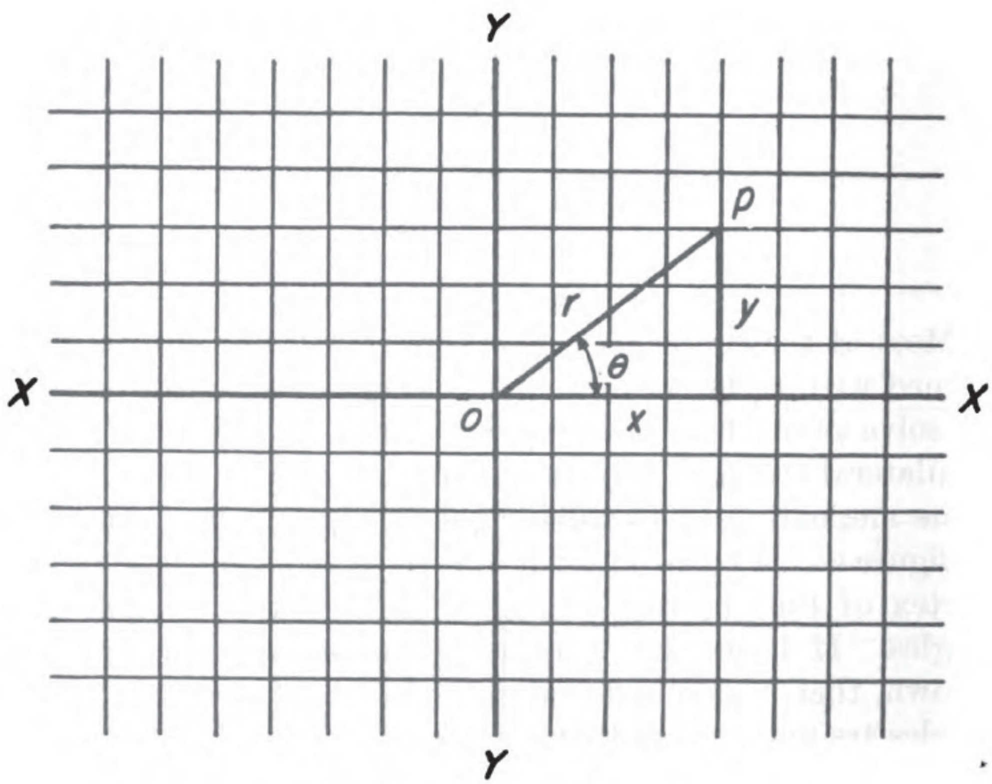


Figure 4–6.—Angle in the first quadrant.

right triangle is shown in the first quadrant. Note that point P has an abscissa of 3 and an ordinate of 4. The hypotenuse $OP=5$. This hypotenuse is formed by the ray generating the angle and is labeled r. So long as this ray is considered to be moving in a counterclockwise or positive direction, it is positive and is not affected by its position in relation to the axes.

Now, if the ray generating the angle moves into the second quadrant, it is obvious that angle θ is no longer an angle of less than 90° but one somewhere between 90° and 180°. (See fig. 4–7.) In order to determine the trigonometric functions of such an angle, the coordinates of point P are determined and a line dropped from point P perpendicular to the x axis. Thus a right triangle is formed as shown in figure 4–7. If point P has the coordinates $x=-3$ and $y=4$ and the ray generating the angle remains a positive 5, these become the values of the sides of the triangle which has been formed.

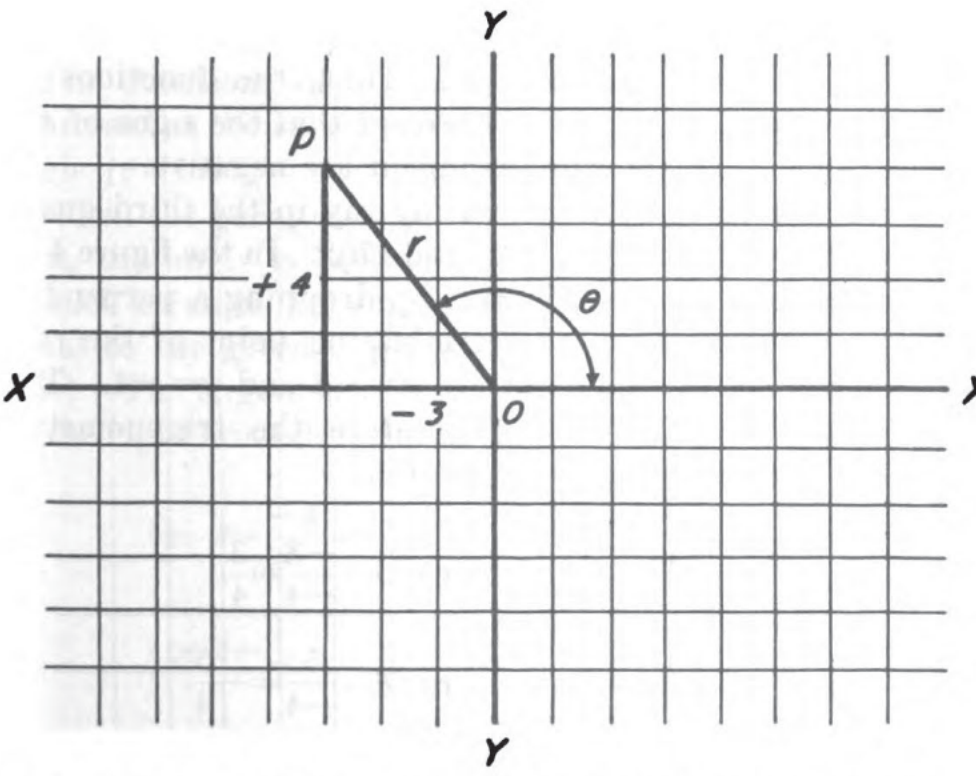


Figure 4–7.—Angle with the generating ray in the second quadrant.

Therefore, using the ratios for the trigonometric functions, we could write:

$$\sin\ \theta = \frac{\text{opposite leg}}{\text{hypotenuse}} = \frac{4}{5},$$

$$\cos\ \theta = \frac{\text{adjacent leg}}{\text{hypotenuse}} = \frac{-3}{5} = -\frac{3}{5},$$

$$\tan\ \theta = \frac{\text{opposite leg}}{\text{adjacent leg}} = \frac{4}{-3} = -\frac{4}{3},$$

$$\cot\ \theta = \frac{\text{adjacent leg}}{\text{opposite leg}} = \frac{-3}{4} = -\frac{3}{4},$$

$$\csc\ \theta = \frac{\text{hypotenuse}}{\text{opposite leg}} = \frac{5}{4},$$

$$\sec\ \theta = \frac{\text{hypotenuse}}{\text{adjacent leg}} = \frac{5}{-3} = -\frac{5}{3}.$$

Of course, the numerical functions of an angle in the second quadrant are the functions of any angle which is the supplement of the given angle. Thus, the functions of θ are equal to those of $180° - \theta$, except that the signs of the cosine, tangent, secant, and cotangent are negative.

An angle formed by a generating ray in the third quadrant is somewhere between 180° and 270°. In the figure 4–8, a right triangle has been formed by dropping a perpendicular from the x axis to the terminating point of the ray. The coordinates of this point are $x = -3$ and $y = -4$. The ray remains a positive 5. Therefore the trigonometric functions of this angle may be written:

$$\sin\ \theta = \frac{-4}{5} = -\frac{4}{5}, \qquad \cot\ \theta = \frac{-3}{-4} = \frac{3}{4},$$

$$\cos\ \theta = \frac{-3}{5} = -\frac{3}{5}, \qquad \csc\ \theta = \frac{5}{-4} = -\frac{5}{4},$$

$$\tan\ \theta = \frac{-4}{-3} = \frac{4}{3}, \qquad \sec\ \theta = \frac{5}{-3} = -\frac{5}{3}.$$

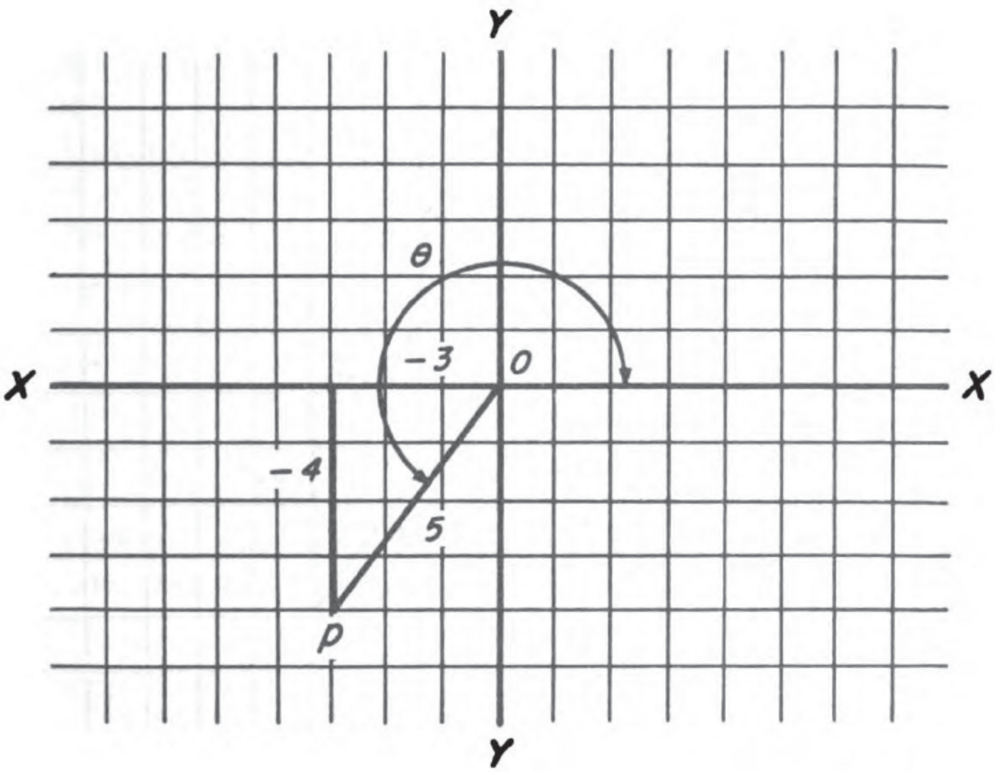


Figure 4–8.—Angle with the generating ray in the third quadrant.

The functions of an angle between 180° and 270° are expressed as the functions of 180° subtracted from the given angle ($\theta-180°$).

When the generating ray has moved to the fourth quadrant, the angle is between 270° and 360°. The functions of such an angle are expressed as the functions of an angle equal to the given angle subtracted from 360°. (See fig. 4–9.) The trigonometric functions may be written in terms of the right triangle formed, thus

$$\sin\ \theta=\frac{-4}{5}=-\frac{4}{5}, \qquad \cot\ \theta=\frac{3}{-4}=-\frac{3}{4},$$

$$\cos\ \theta=\frac{3}{5}, \qquad \csc\ \theta=\frac{5}{-4}=-\frac{5}{4},$$

$$\tan\ \theta=\frac{-4}{3}=-\frac{4}{3}, \qquad \sec\ \theta=\frac{5}{3}.$$

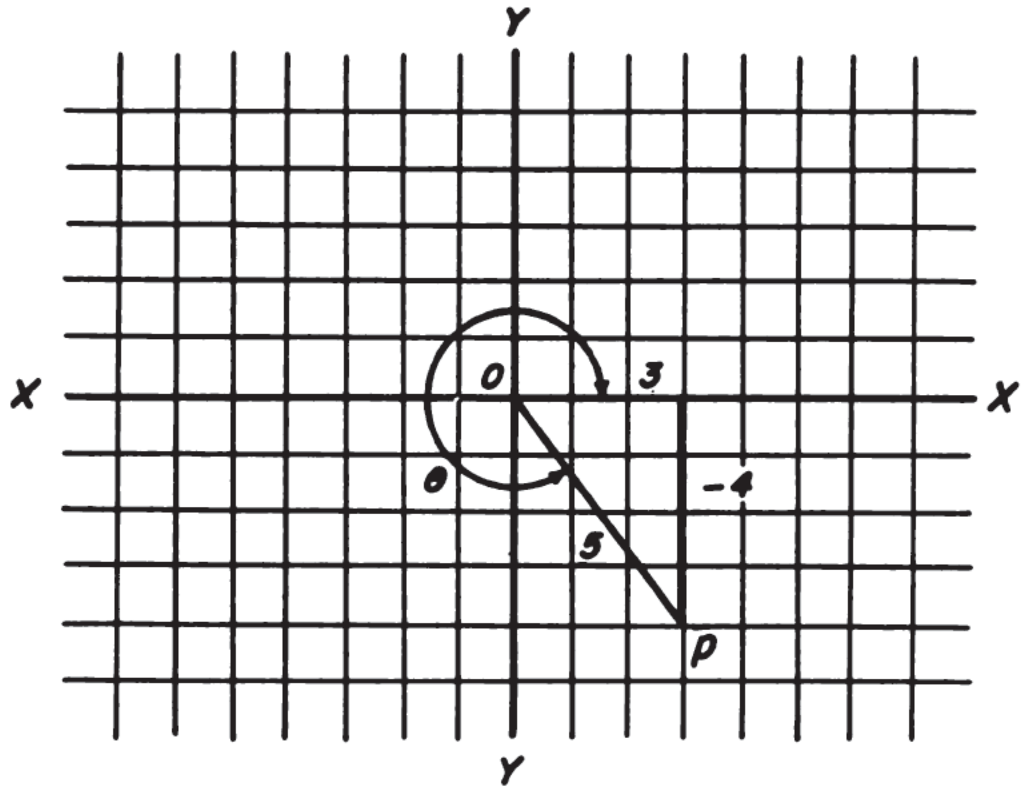


Figure 4–9.—Angle with the generating ray in the fourth quadrant.

The table below summarizes what has been discussed concerning the signs for the functions of angles in different quadrants.

Quadrant	Sin	Cos	Tan	Cot	Sec	Csc
I (0° to 90°)	+	+	+	+	+	+
II (90° to 180°)	+	−	−	−	−	+
III (180° to 270°)	−	−	+	+	−	−
IV (270° to 360°)	−	+	−	−	+	−

GRAPHS

Although the quals do not call specifically for a knowledge of graphs, it will pay you to study carefully chapters 6, 7, and 8 in NavPers 10070–A. If you are a topographic draftsman, much of your work will be concerned with grids. If your billet is in one of the engineering drafting fields, an

understanding of dependence or relationship will be invaluable. Any draftsman should know how to construct a graph.

A graph shows the relationship between two values. The grid system used in many graphs is called the RECTANGULAR COORDINATE SYSTEM. This system is actually basic to much of mathematics, including trigonometry. In the rectangular coordinate system, the values to be plotted are spaced at equal intervals along 2 axes which intersect at right angles to form 4 quadrants. The point of intersection of the axes is called the ORIGIN. The horizontal axis is commonly called the x axis; and the vertical axis, the y axis. When a point is located on a graph, its value according to the x axis is called the ABSCISSA and its value according to the y axis is called the

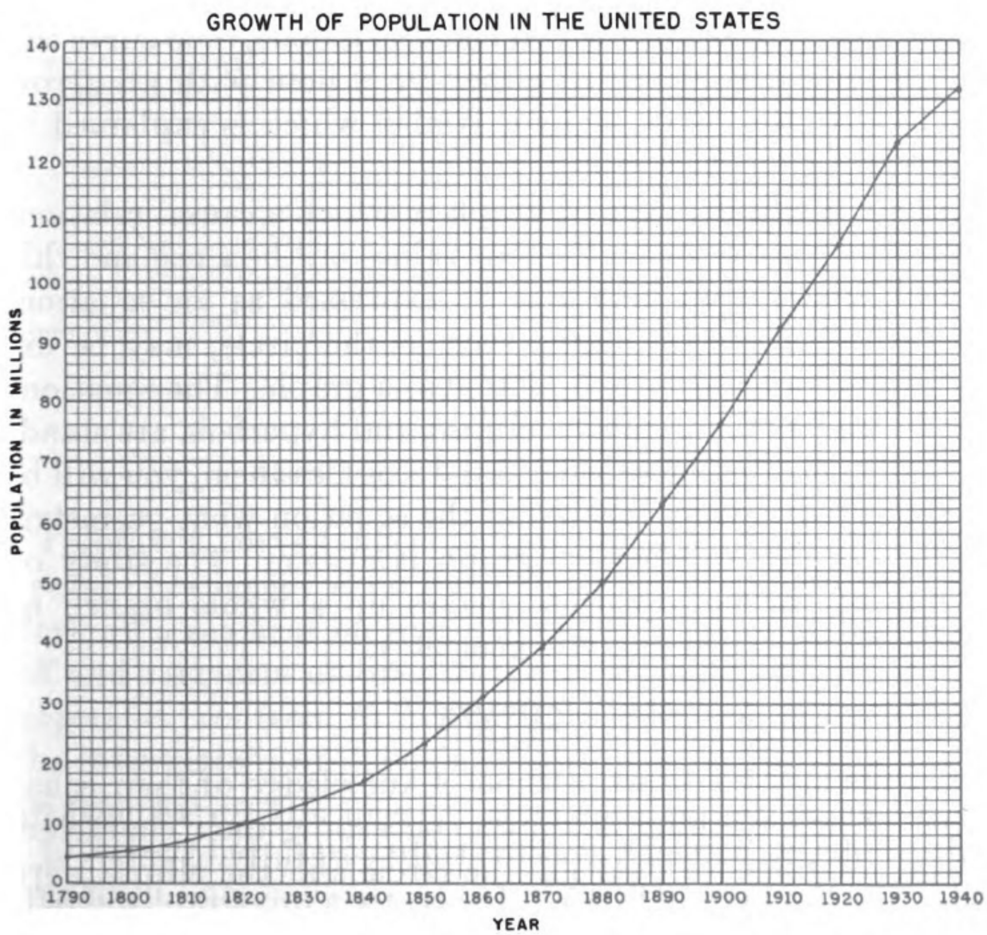


Figure 4–10.—Growth of population in the United States, 1790–1940.

ORDINATE. Together these values are the coordinates of the point. The abscissa is always first when the coordinates of a point are given. A line drawn through plotted points on a graph is called a CURVE, although it may be a straight line.

In one type of graph, no causal relationship exists between the two values shown in the graph. It is merely a picture of changing conditions. For example, in graphs showing changes in population over periods of time, the population count does not vary because of variations in the time interval. Such a graph is shown in figure 4–10. Notice that the lines of the axes are at the edge of the grid, since no negative values are included.

Two or more graphs are sometimes combined. That is, several sets of coordinates are plotted in reference to the same pair of axes. In this way the relation existing between all of them may be shown. When this is done, each curve can be conveniently identified either by a note with an arrow pointing to the curve, or by a symbol which is explained in a legend.

There is another type of graph in which a causal relationship does exist between the two values on the axes, and this causal relationship may also be expressed as an equation. In fact, a geometric figure, such as the circle, may be expressed as an equation and plotted as a graph. The equations for forms like the parabola, ellipse, and hyperbola are standard, and once you have learned to recognize them, you will be able to predict from looking at the equation what geometric form it will take when its graph is drawn. The study of curves of various equations makes up a whole branch of mathematics called analytic geometry.

CURVES

Curves may be drawn without a knowledge of their equations when something is known concerning their characteristics. Methods of drawing the circle and the ellipse were discussed in *Draftsman 3*, and the four-point method of drawing an approximate ellipse is given in chapter 3 of this training course.

To draw a REVERSE OR OGEE CURVE tangent to two lines, erect a perpendicular at point A and drop one at point B as shown in figure 4–11A. Connect the points A and B with a line as shown in figure 4–11B. Assume a point C on this line through which the curve will pass. This point may be the midpoint of the line, if equal arcs are desired. Bisect AC and CB, as shown in figure 4–11C. The intersection of these lines with the perpendiculars from points A and B are the centers of the required arcs. Complete the curve as shown in figure 4–11D.

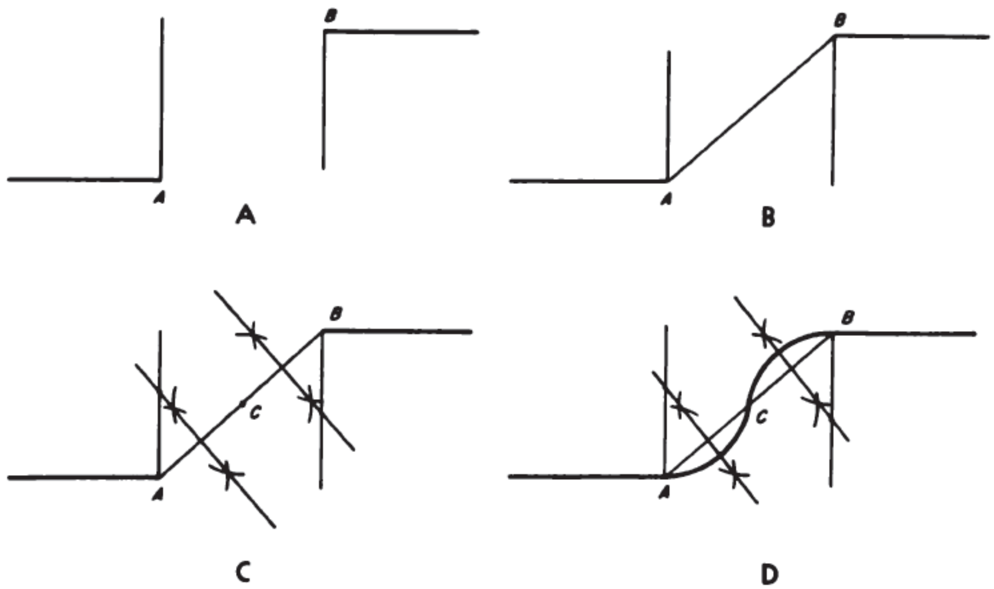


Figure 4–11.—Reverse or ogee curve.

To draw a curve tangent to three intersecting lines, select a point of tangency E on line BC, as shown in figure 4–12A. Mark off a segment on line AB which is the same length as BE and a segment on line CD the same length as EC. Erect perpendiculars from E, F, and G, as shown in figure 4–12B. The intersections of these perpendiculars are the centers for the required arcs.

CONICS.—The four curves—circle, ellipse, parabola, and hyperbola—are called conics because they can be thought of as sections of a cone. (See fig. 4–13.) Conics can be expressed as algebraic equations and plotted as described in

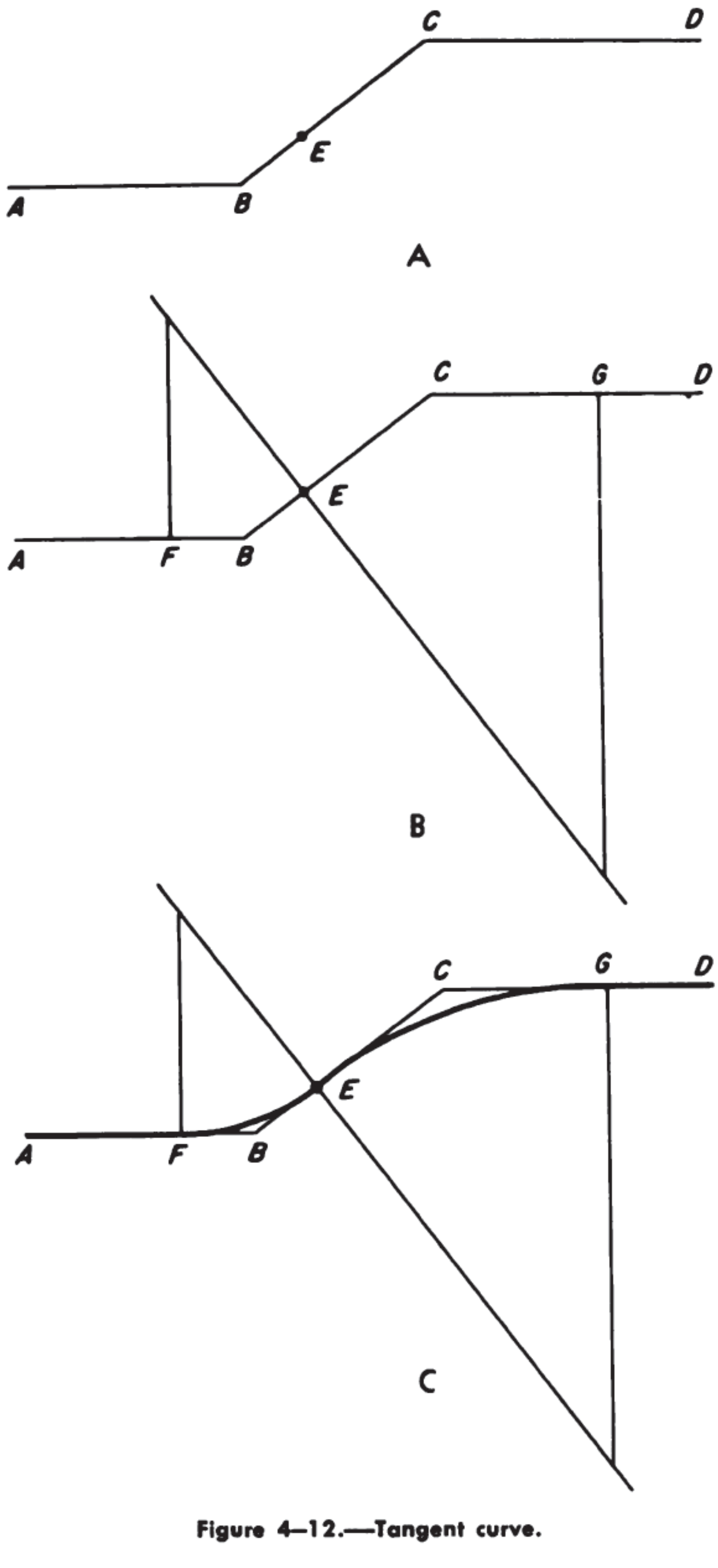


Figure 4–12.—Tangent curve.

the section on graphs. They can also be drawn with a knowledge of their equations, if certain of their characteristics are given. For example, the circle can be drawn if its radius is known.

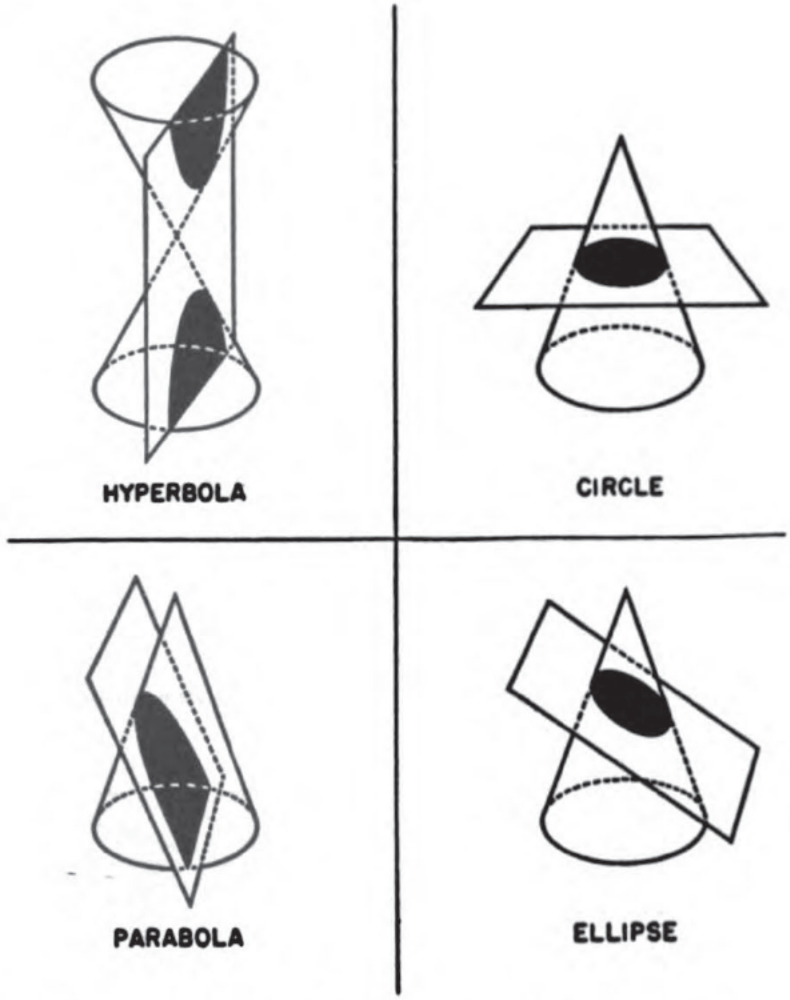


Figure 4–13.—The sections of a cone which form the conics.

An ELLIPSE is generated by a point moving so that the sum of its distance from two fixed points, called the focuses, is a constant equal to the major axis. This definition is well illustrated in the pin-and-string method of drawing an ellipse shown in figure 4–14. Most of the ellipses you will be required to draw will be the oblique or isometric views of circles.

The reflector of a searchlight is a parabolic curve, and the path of a projectile follows a parabolic curve. A PARABOLA

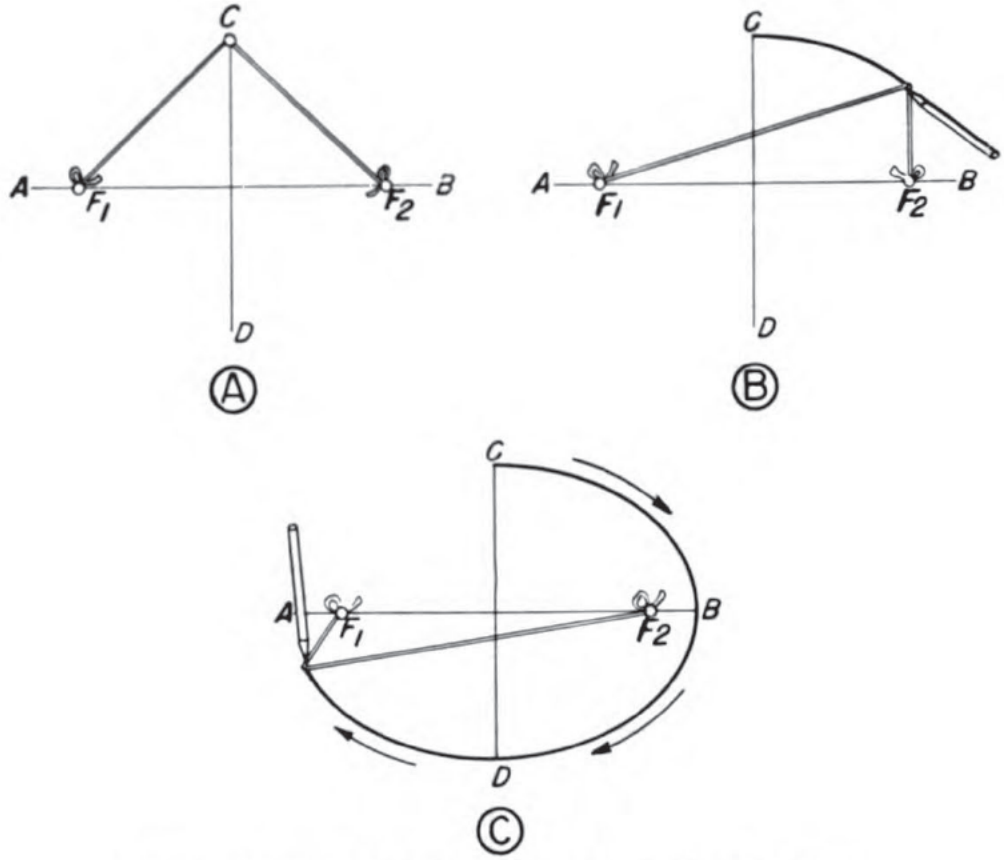


Figure 4–14.—Pin-and-string method of drawing an ellipse.

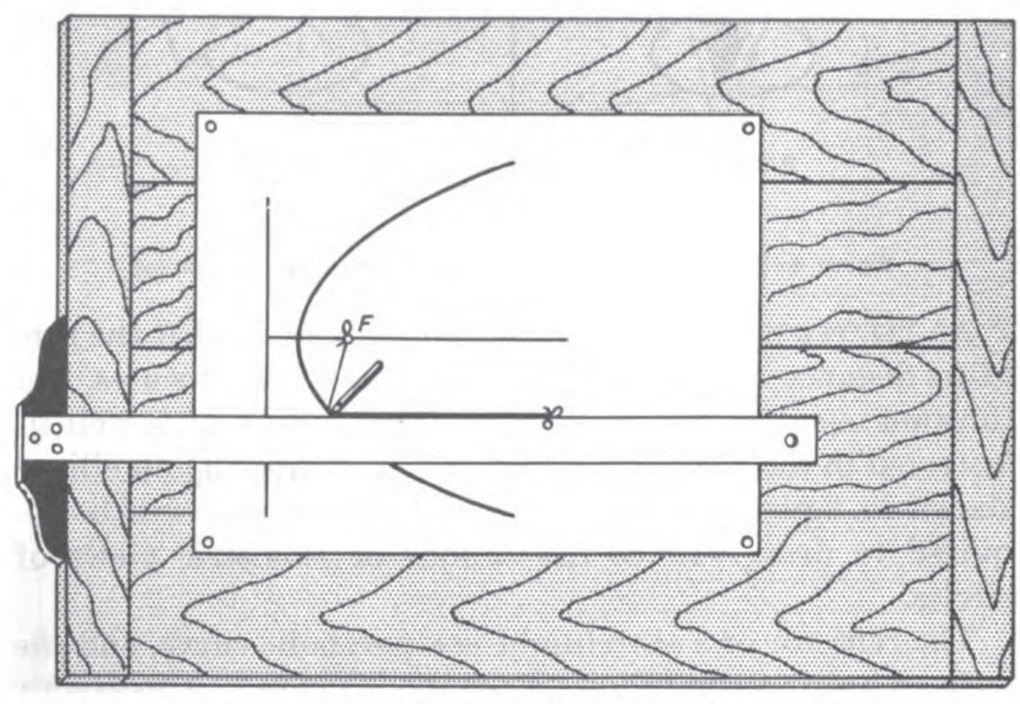


Figure 4–15.—Pin-and-string method of drawing a parabola.

is a curve any point of which is equidistant from a fixed point, called the FOCUS, and a fixed line, called the DIRECTRIX. This may be illustrated by the pin-and-string method of drawing a parabola which is shown in figure 4–15. The string is attached at the focus and at a point selected at random on the straightedge. The location of the point on the straightedge depends on the desired extent of the curve. The string must be kept taut, and the pencil kept against

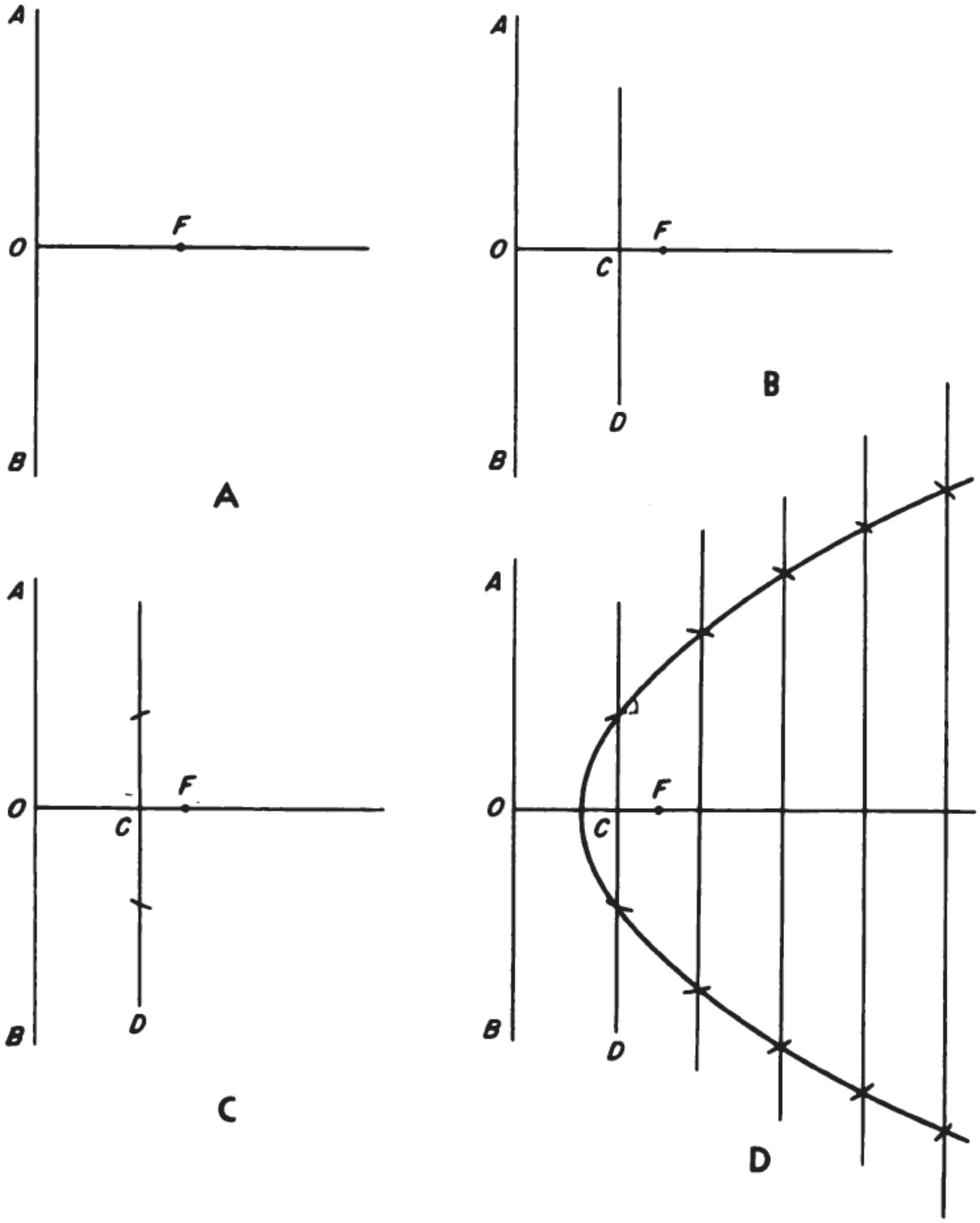


Figure 4–16.—Method of drawing a parabola.

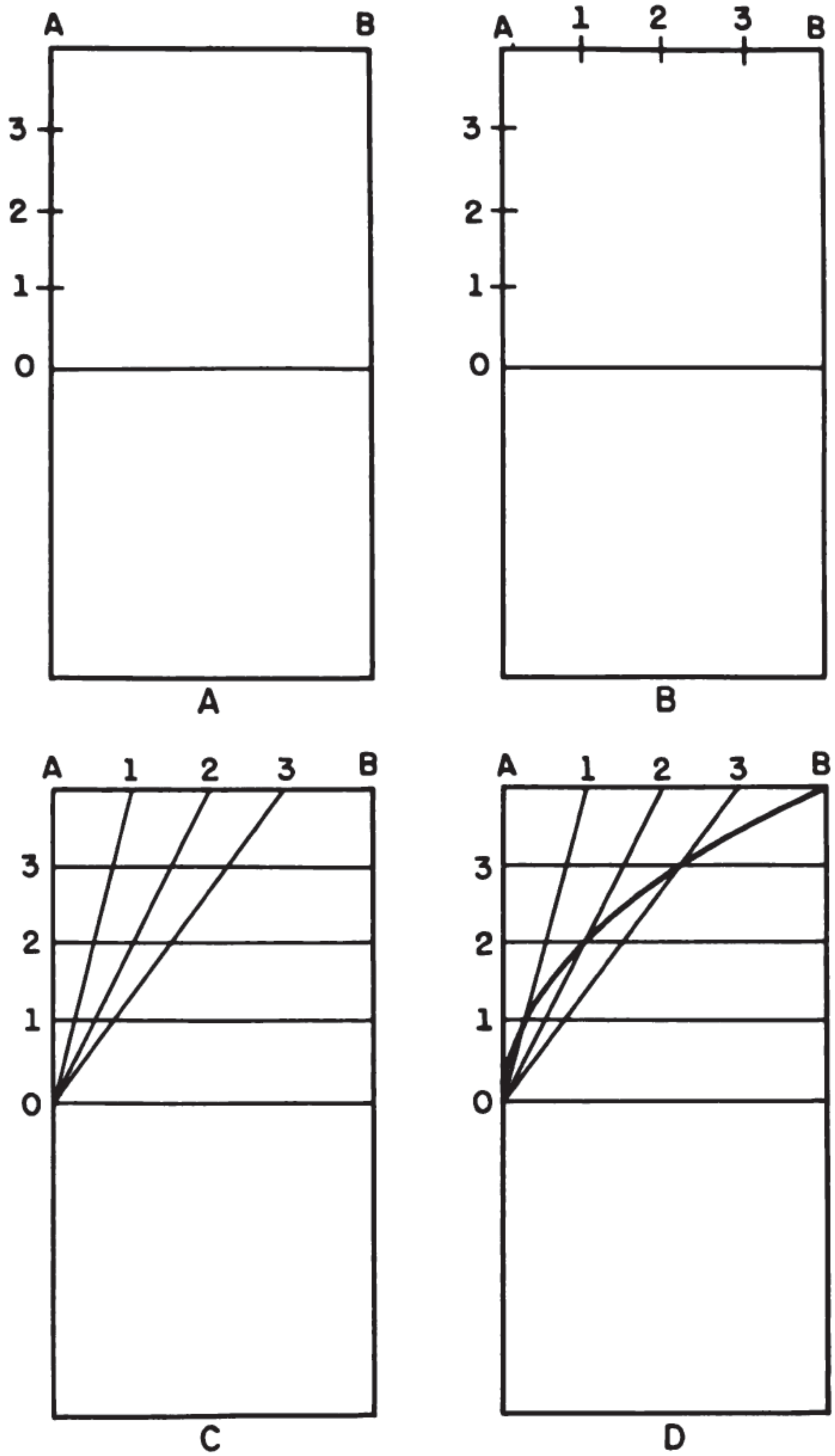


Figure 4–17.—Method of drawing a parabola in a rectangle.

the straightedge. As the straightedge is moved, the pencil describes the curve of the parabola.

When the focus and the directrix of a parabola are given, draw the axis of the parabola through the focus and perpendicular to the directrix. (See fig. 4–16A.) Through any point on this perpendicular, draw a line parallel to the directrix, as shown in figure 4–16B. With the distance, OC, from the directrix as a radius and with the focus F as a center, draw an arc intersecting this line. (See fig. 4–16C.) This intersection is a point on the curve. Repeat the operation until enough points have been located to establish the curve.

Often when a parabola is required, either the dimensions of the enclosing rectangle or the width and depth of the parabola are given. In this case, draw the axis of the parabola in the center of the rectangle. Divide half the width of the parabola into a number of equal spaces, as shown in figure 4–17A. Then divide the end of the rectangle AB into the same number of divisions, also equally spaced, as shown in figure 4–17B. From these divisions, draw lines which converge at the point O shown in figure 4–17C, and from the corresponding divisions on OA, draw lines which are parallel to the axis. The intersections of the two sets of lines will be the points on the curve, as shown in figure 4–17D.

A curve of parabolic form, such as is often used in machine design, may be drawn by first drawing a right angle, as shown in figure 4–18A. Each side of the angle is divided into the same number of equally spaced divisions. These divisions are then numbered as shown in figure 4–18B, and the corresponding numbers are connected. The resulting tangent curve will have a parabolic form. Figures 4–18C and 4–18D show curves constructed from angles other than right angles.

A HYPERBOLA is generated by a point moving so that the difference of its distance from two fixed points, called the focuses, is constant. This constant is equal to the TRANSVERSE AXIS shown as AB in figure 4–19. The CONJUGATE

AXIS is perpendicular to the transverse axis. A common example of a hyperbola is the curve formed on a side of a hexagonal bolt head by the chamfers.

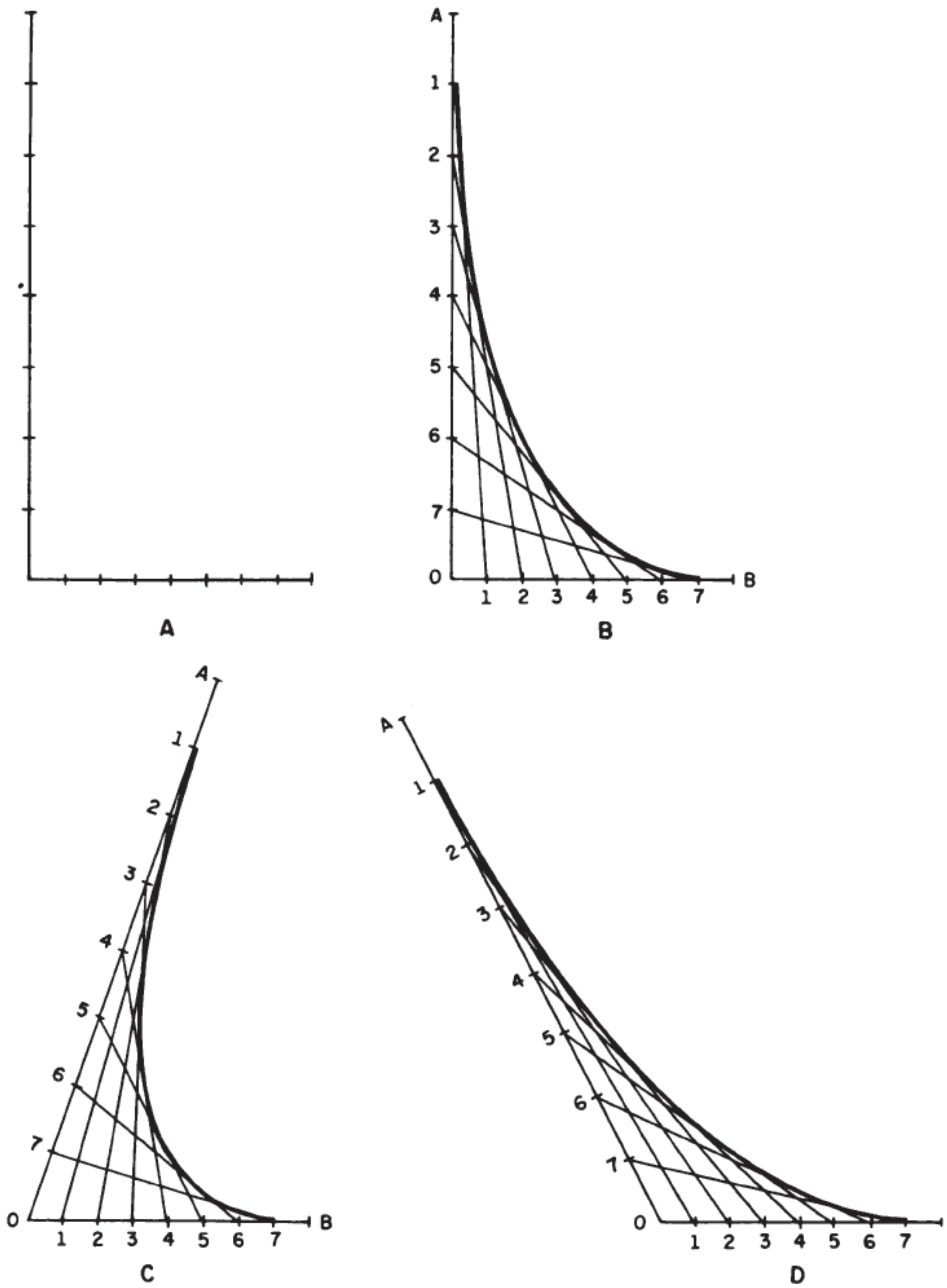


Figure 4–18.—Method of drawing a curve of parabolic form.

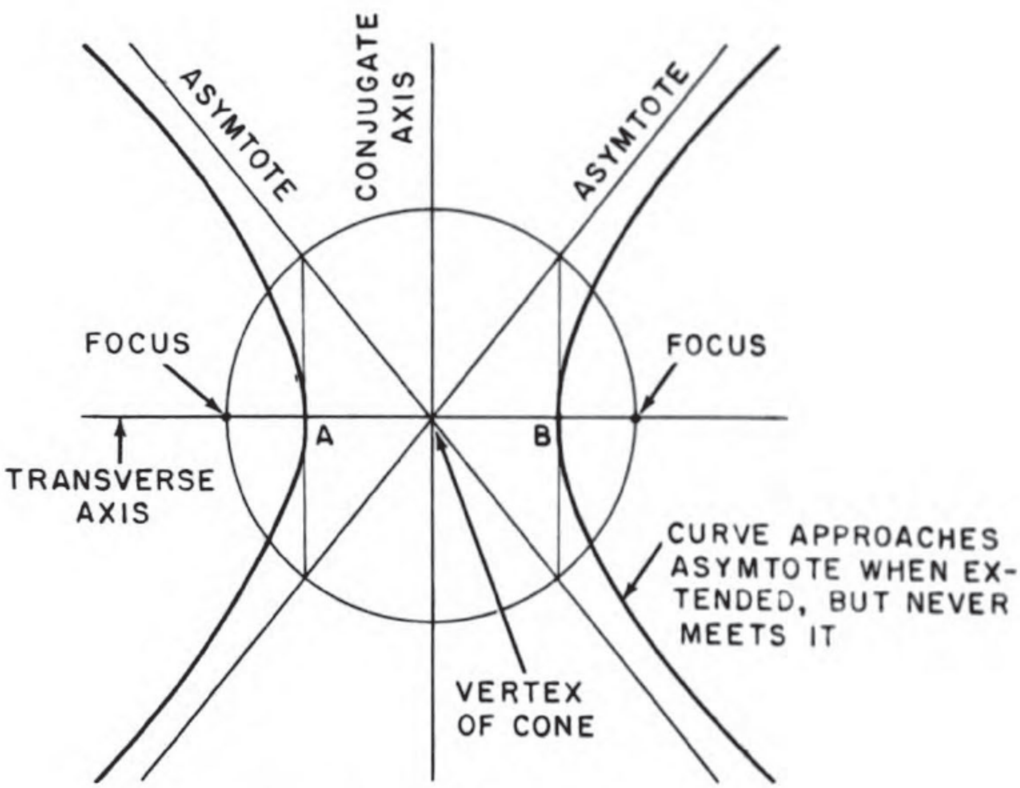


Figure 4–19.—The plane of a hyperbola.

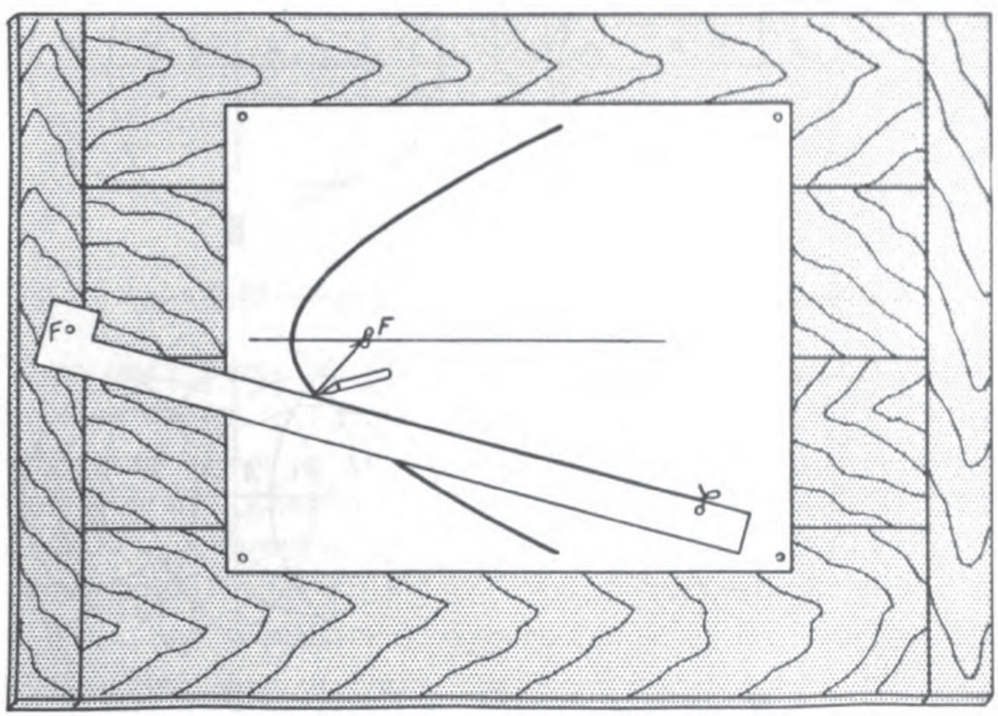


Figure 4–20.—Pin-and-string method of drawing a hyperbola.

The pin-and-string method may be used to draw a hyperbola, as shown in figure 4–20. The straightedge is attached at one focus F and one end of the string at the other focus F'. The other end of the string is attached to the straightedge, and its distance from F depends on the desired extent of the curve. When the straightedge is revolved with a pencil point against it and the string kept taut, a hyperbola may be drawn.

To construct the curve geometrically, select any point, such as P, on the transverse axis extended. Using the distance from this point to the near end of the transverse axis (BP) as a radius and with the focuses as centers, draw arcs as shown in figure 4–21A. Then, using the distance from the point P to the far end of the transverse axis (AP) and with the focuses as centers, draw arcs intersecting the first arcs. The intersections of the arcs are points on the curve. (See fig. 4–21B.) Select a second point P' on the extension

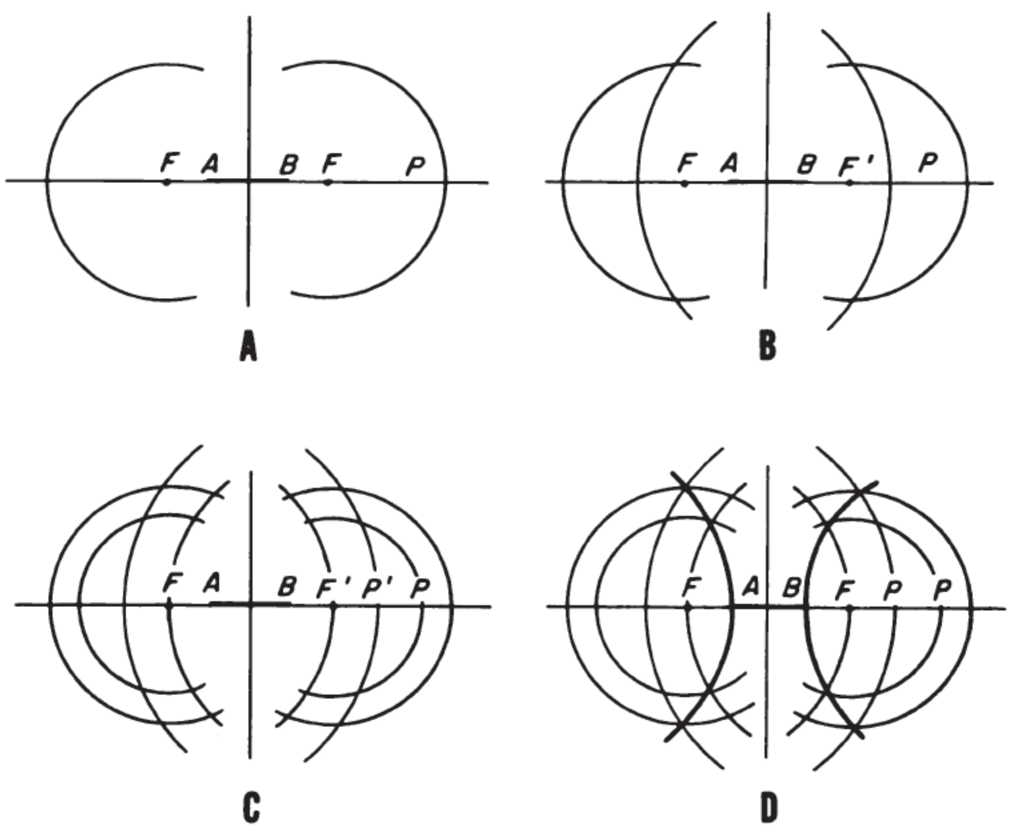


Figure 4–21.—Method of drawing a hyperbola.

of the transverse axis and perform the same operation, as shown in figure 4–21C. This may be done as often as necessary to define the curve.

The ASYMPTOTES of the hyperbola are very important in tracing the curve and studying its properties. To draw the asymptotes, first draw a circle with a diameter equal to the distances between the focuses, as shown in figure 4–22A.

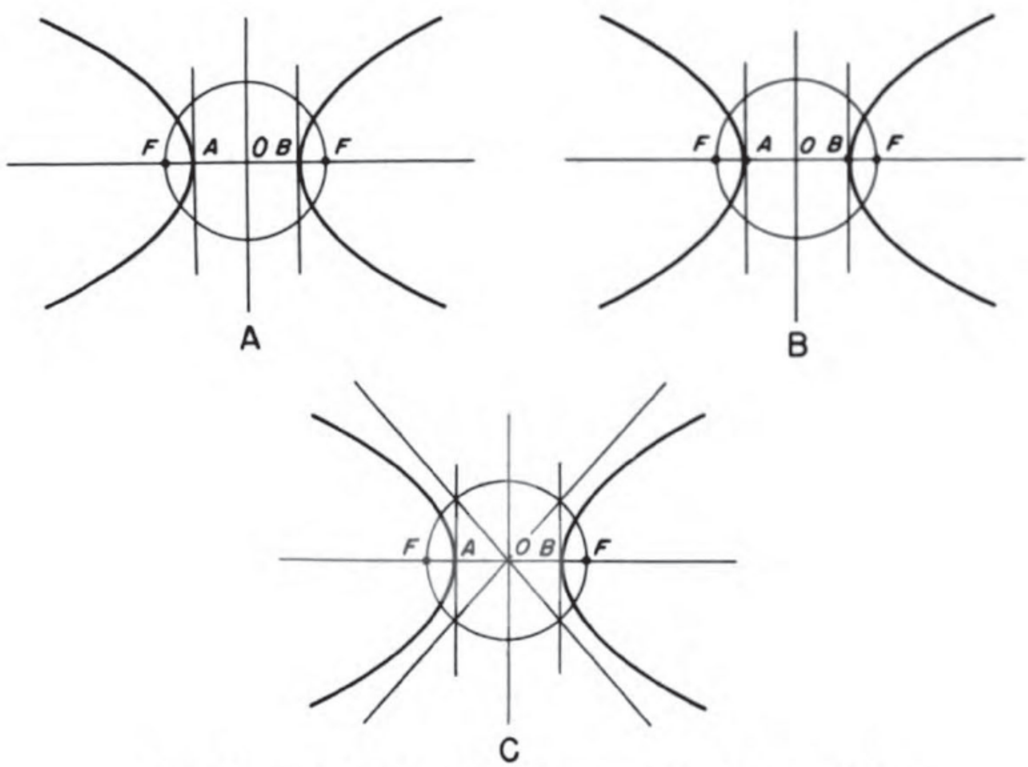


Figure 4–22.—Method of drawing asymptotes of a hyperbola.

Then erect perpendiculars from the ends of the transverse axis, as shown in figure 4–22B. When the points of intersection of these perpendiculars with the circumference of the circle are connected by lines with the center of the circle as shown in figure 4–22C, an **X** is formed which defines the asymptotes.

When an equilateral hyperbola is to be drawn, the asymptotes form a right angle. When the location of a point P in relation to the asymptotes is given, draw the asymptotes shown as AO and OB in figure 4–23. Locate the

point P on the curve and draw lines through it perpendicular to the asymptotes, as shown in figure 4–23A. Mark any points on PD and number them 1, 2, 3, 4, etc., as shown in figure 4–23B. Draw a series of lines through these points parallel to OB, and a second series of lines converging on O through the same points. (See fig. 4–23C.) From the intersection of these lines with CP extended draw perpendiculars to OB. (See fig. 4–23D.) The intersections of these perpendiculars with the parallel lines through the points on PD give points on the curve.

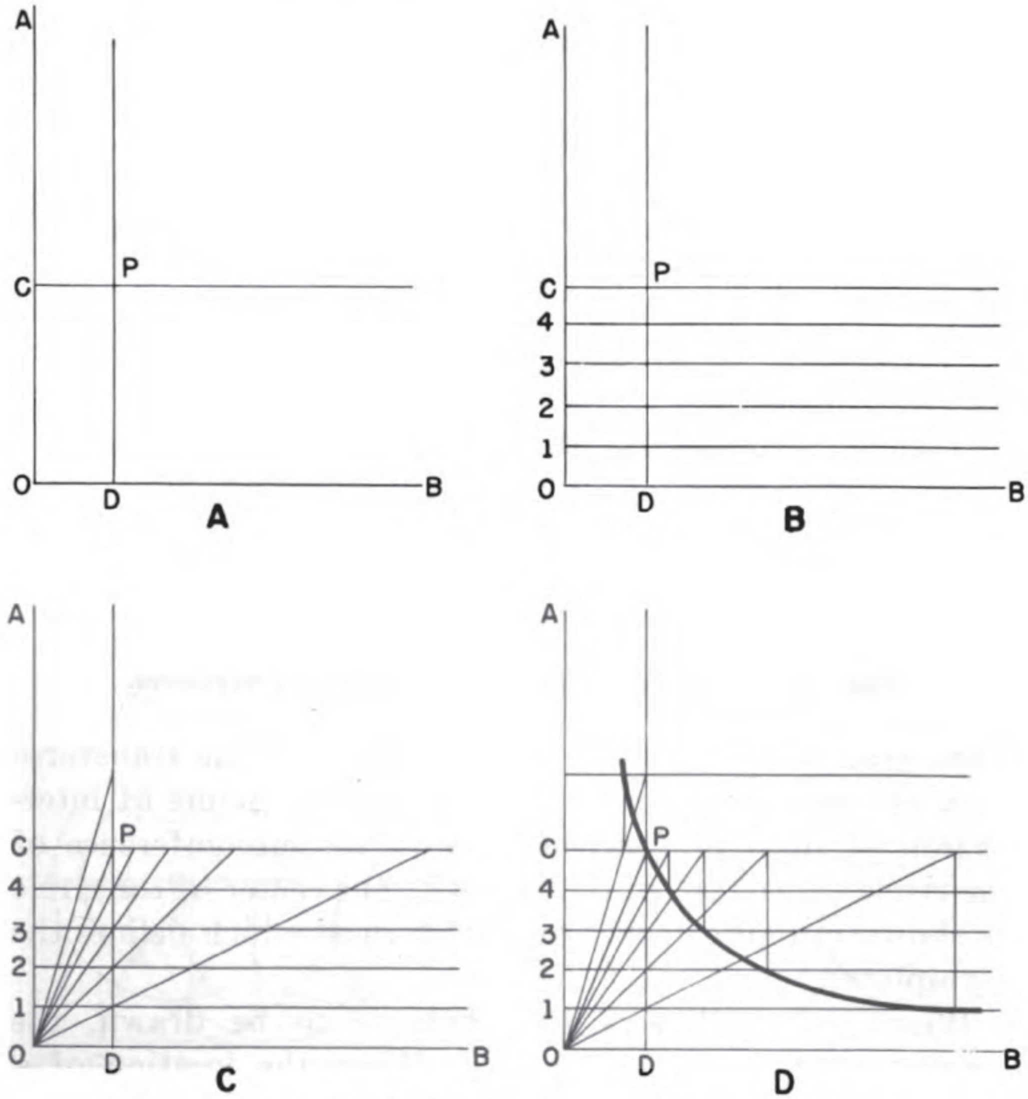


Figure 4–23.—Method of drawing an equilateral hyperbola.

CYCLOIDAL CURVES.—A CYCLOID is generated by a point on the circumference of a circle that is rolled along a straight line. An EPICYCLOID is generated if the circle is rolled along the outside of another circle. A HYPERCYCLOID is generated

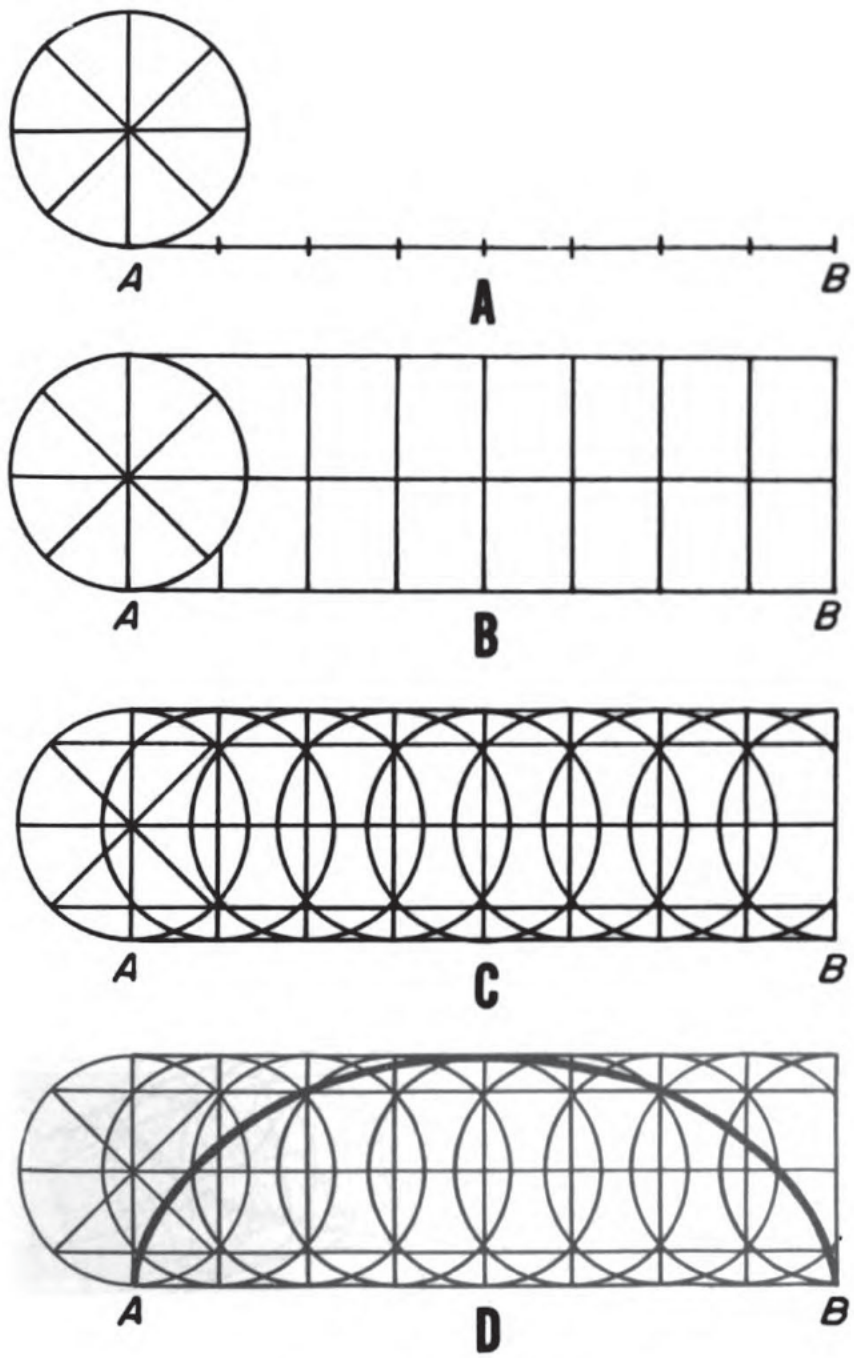


Figure 4–24.—Method of drawing a cycloid.

if the circle is rolled along the inside of another circle. These curves are sometimes used in gear designs.

To draw a cycloid when the circle and the straight line are given, first draw the circle tangent to the line. (See fig. 4–24.) Then divide the circle into a convenient number of equal parts. Lay off on the line the rectified length of the circumference of the circle, and divide this into the same number of parts as the circle, as shown in figure 4–24A.

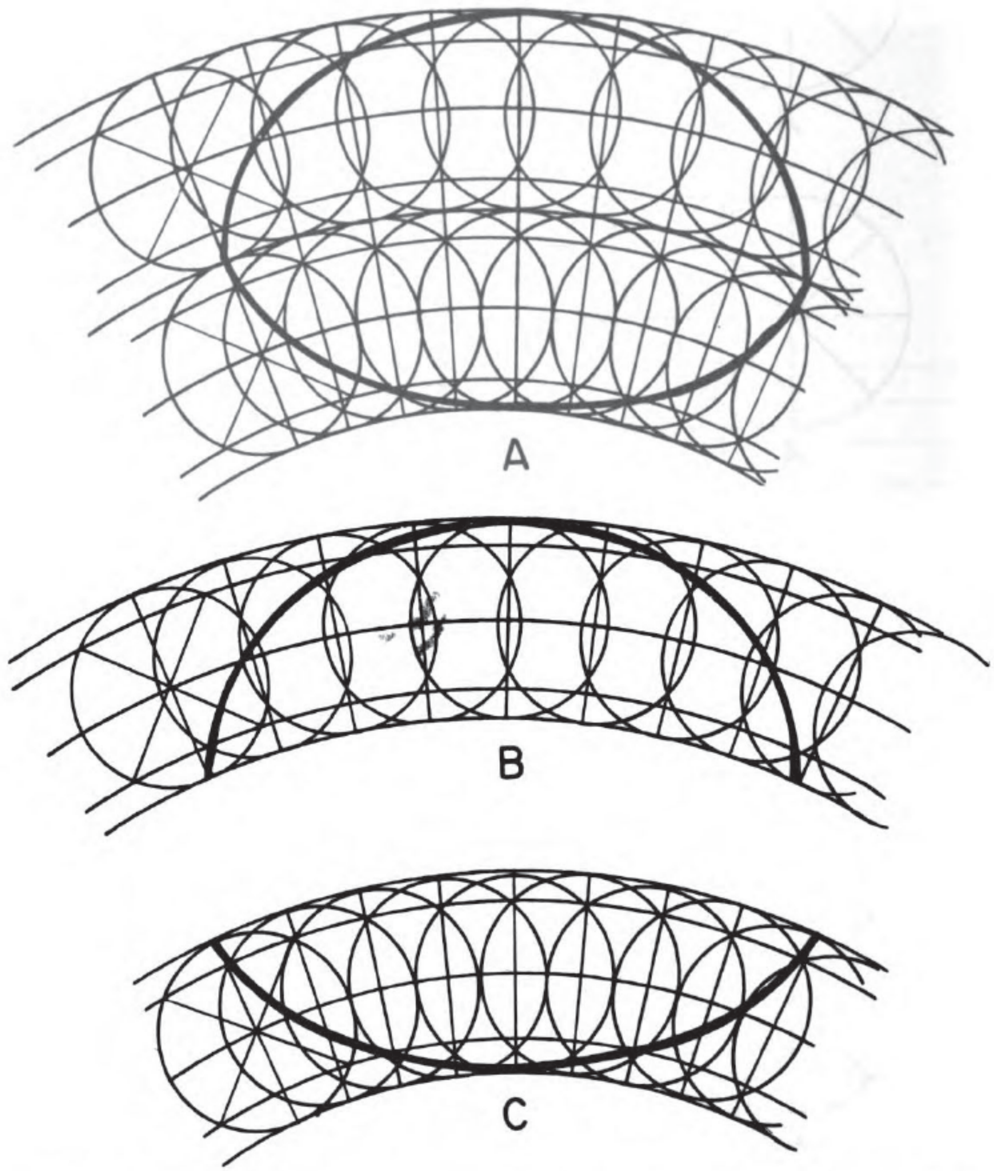


Figure 4–25.—A. Epicycloid and hypocycloid. B. Epicycloid. C. Hypocycloid.

Erect perpendiculars from these divisions and extend a line from the center of the circle parallel to AB, as shown in figure 4–24B. The intersections of this line with the perpendiculars locates the center of the moving circle at each successive division. Using these centers, draw circles with the same radius as the given circle, and then draw lines from the divisions on the original circle parallel to line AB and intersecting the arcs of the other circles, as shown in figure 4–24C. These intersections are the points of the curve.

The epicycloid and hypocycloid are drawn in the same manner, except that instead of a straight line, an arc is drawn which represents the outside or inside of another circle. Therefore, instead of perpendiculars, normals are drawn to this arc. The radius for both circles should be given. (See fig. 4–25.)

A NORMAL is a line which is perpendicular to a tangent at a point on an arc. In order to draw a normal, draw a tangent to the point on the arc, and erect a perpendicular from this tangent.

INVOLUTE.—An involute is the curve that might be traced by a point on a cord that is being unwound from a line, a triangle, a square or another polygon, or a circle. Figure 4–26

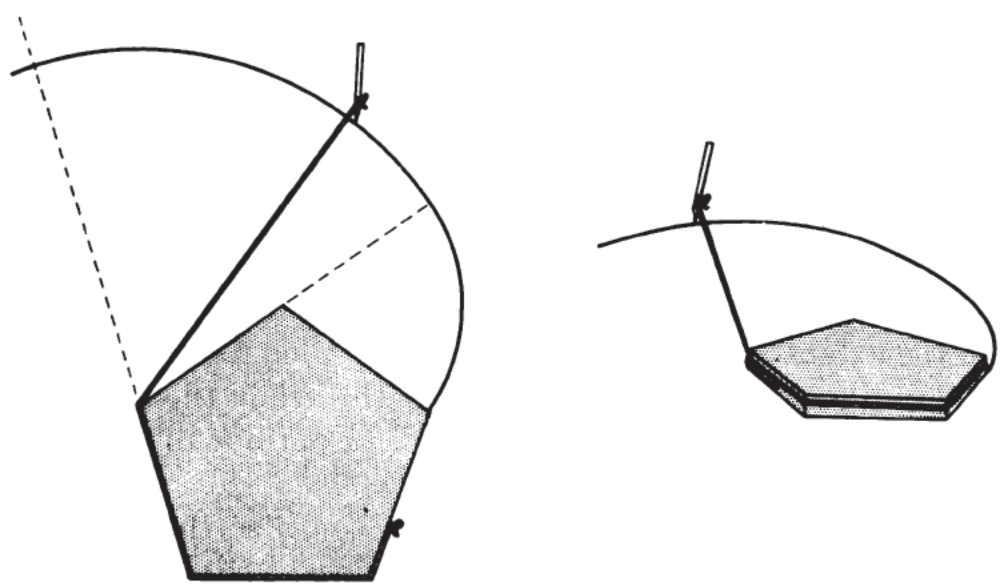


Figure 4–26.—Pin-and-string method of drawing an involute of a pentagon.

illustrates the pin-and-string method of drawing the involute of a pentagon.

To draw an involute of a line AB, extend the line as shown in figure 4–27A. Using the length AB as a radius and A as a center, draw a semicircle, as shown in figure 4–27B. Then, using BC as the radius and B as the center, draw a second semicircle continuing the curve, as shown in figure 4–27C. Then, with CD as the radius and C as the center, draw the next arc, as shown in figure 4–27D. Proceed in the same manner until the curve is the desired size.

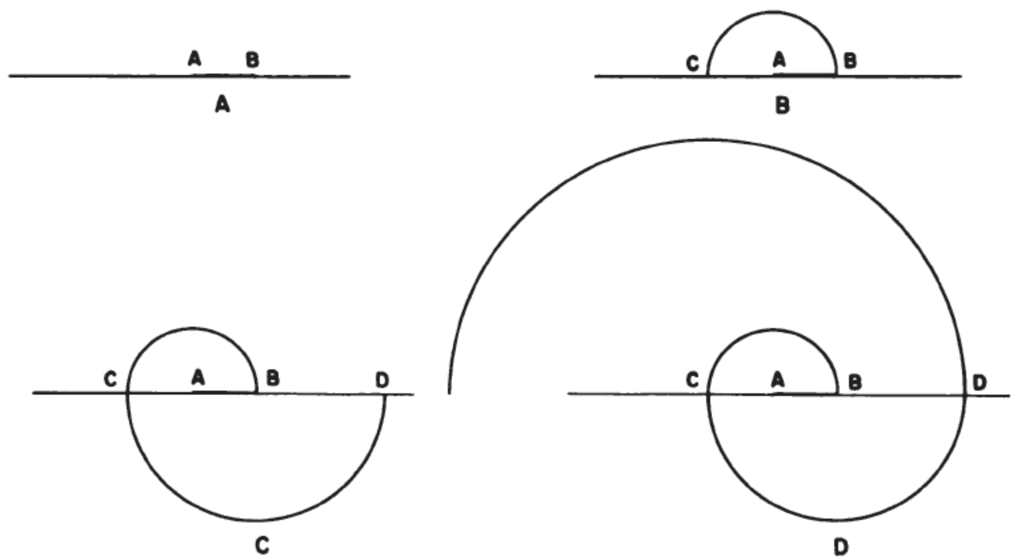


Figure 4–27.—Method of drawing the involute of a line.

To draw the involute of a triangle, extend the sides as shown in figure 4–28A. Using one side AB as a radius, and A as the center, draw an arc from B to the extension of side AC, as shown in figure 4–28B. Using a radius the length of AC plus its extension, and with C as the center, draw an arc to the extension of side BC. With BC plus its extension as the radius and C as the center, draw the arc to the extension of side AB, as shown in figure 4–28C. Continue in this manner until the figure is the desired size.

To draw the involute of a circle, consider the circle as a polygon with a great number of sides. Divide the circumference of the circle into a number of equal parts. Then

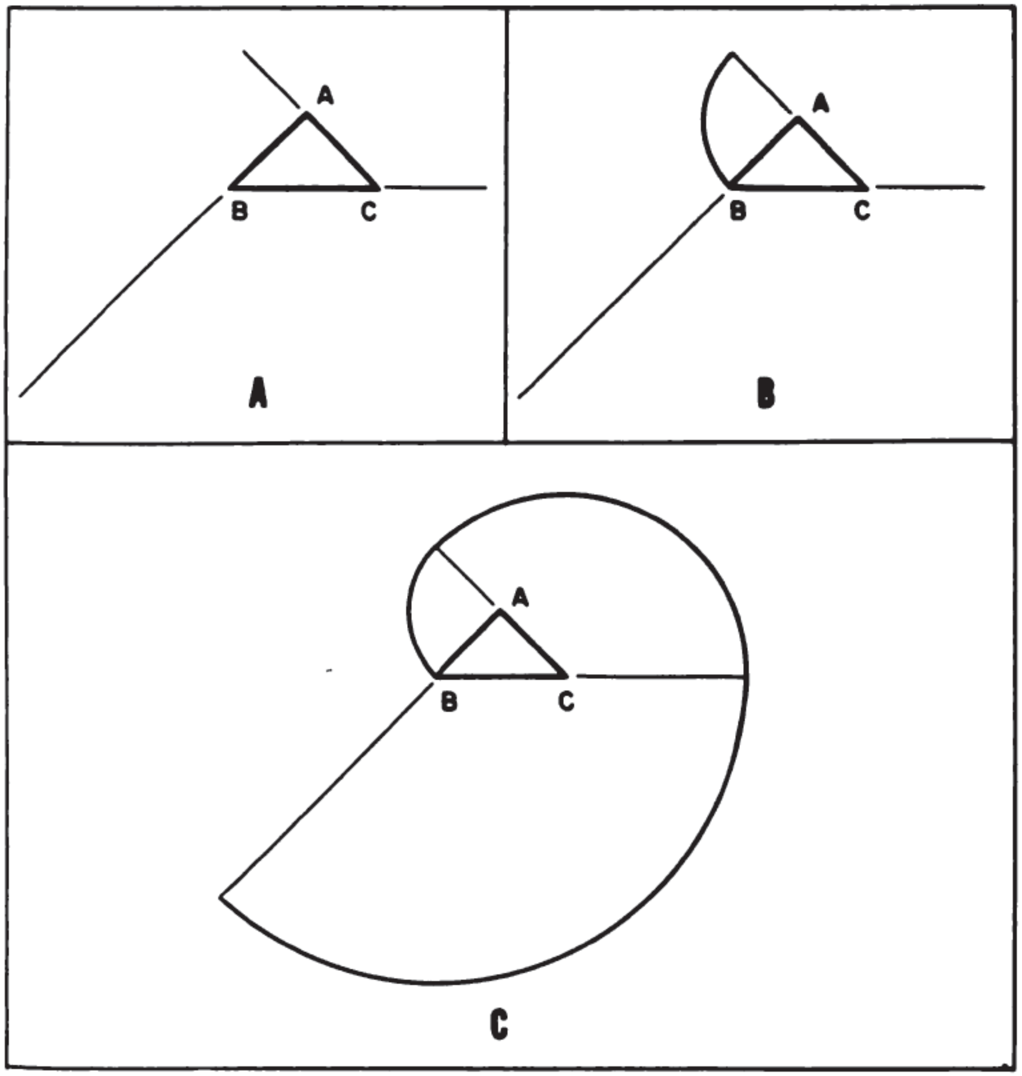


Figure 4–28.—Method of drawing the involute of a triangle.

draw tangents from each division, as shown in figure 4–29A. With the rectified distance of a division as a radius, draw an arc from one division to intersect the tangent of the next division, as shown in figure 4–29B. With the intersection point on this tangent to the point of tangency as a radius, draw an arc to intersect the next tangent. (See fig. 4–29C.) Continue until the figure is of the required size.

Spiral.—The spiral is generated by a point moving around a fixed point, its distance increasing uniformly with the angle. To draw a spiral which makes one turn in a given

circle, divide the circle into a number of equal parts and number these parts in succession. (See fig. 4–30A.) Then divide the radius of the circle into the same number of parts and number them from the center outward, as shown in figure 4–30A. Using the center of the circle as a center, draw

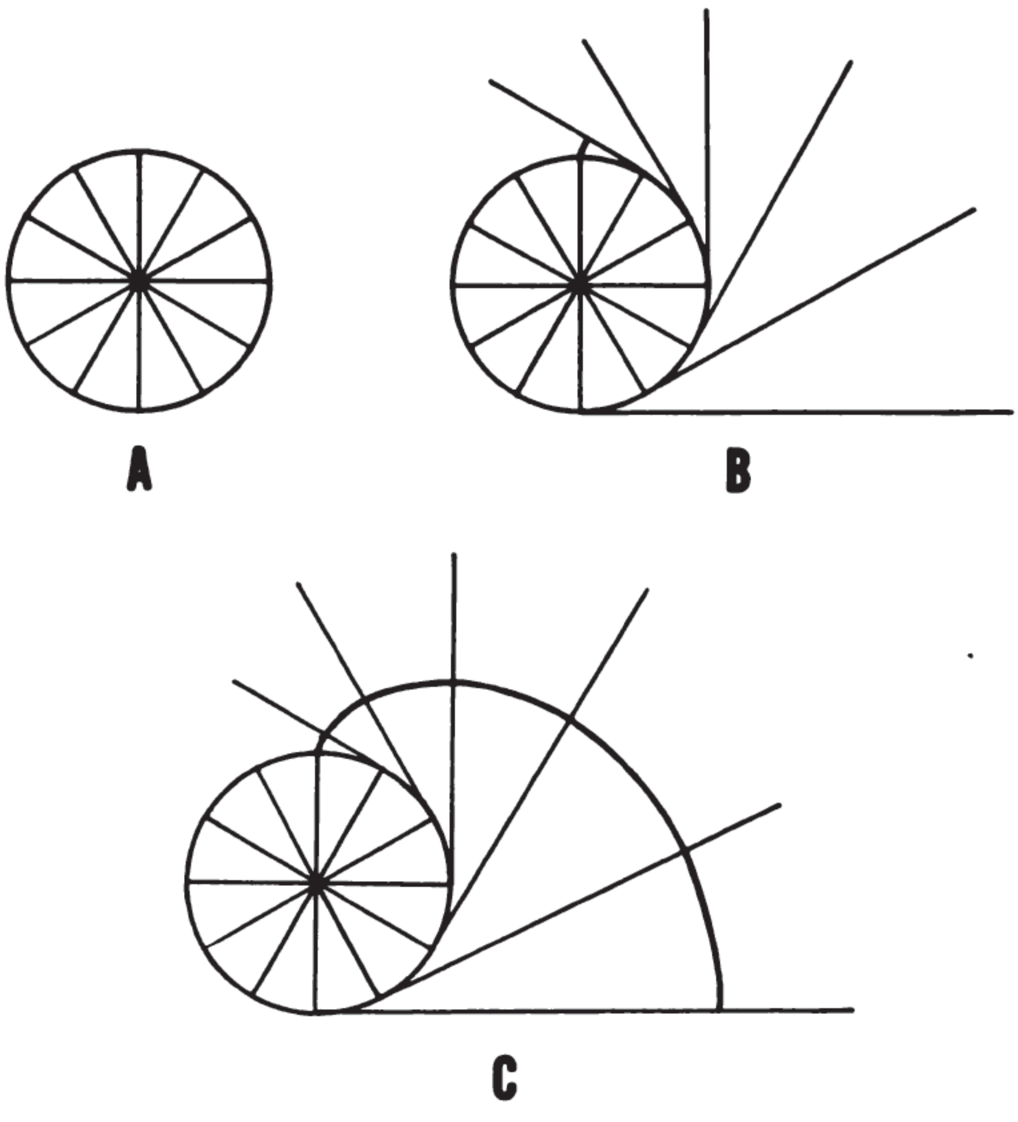


Figure 4–29.—Method of drawing the involute of a circle.

from each of the numbered divisions an arc which intersects a corresponding numbered division on the radius, as shown in figure 4–30B. These intersections are the points of the curve, as shown in figure 4–30C.

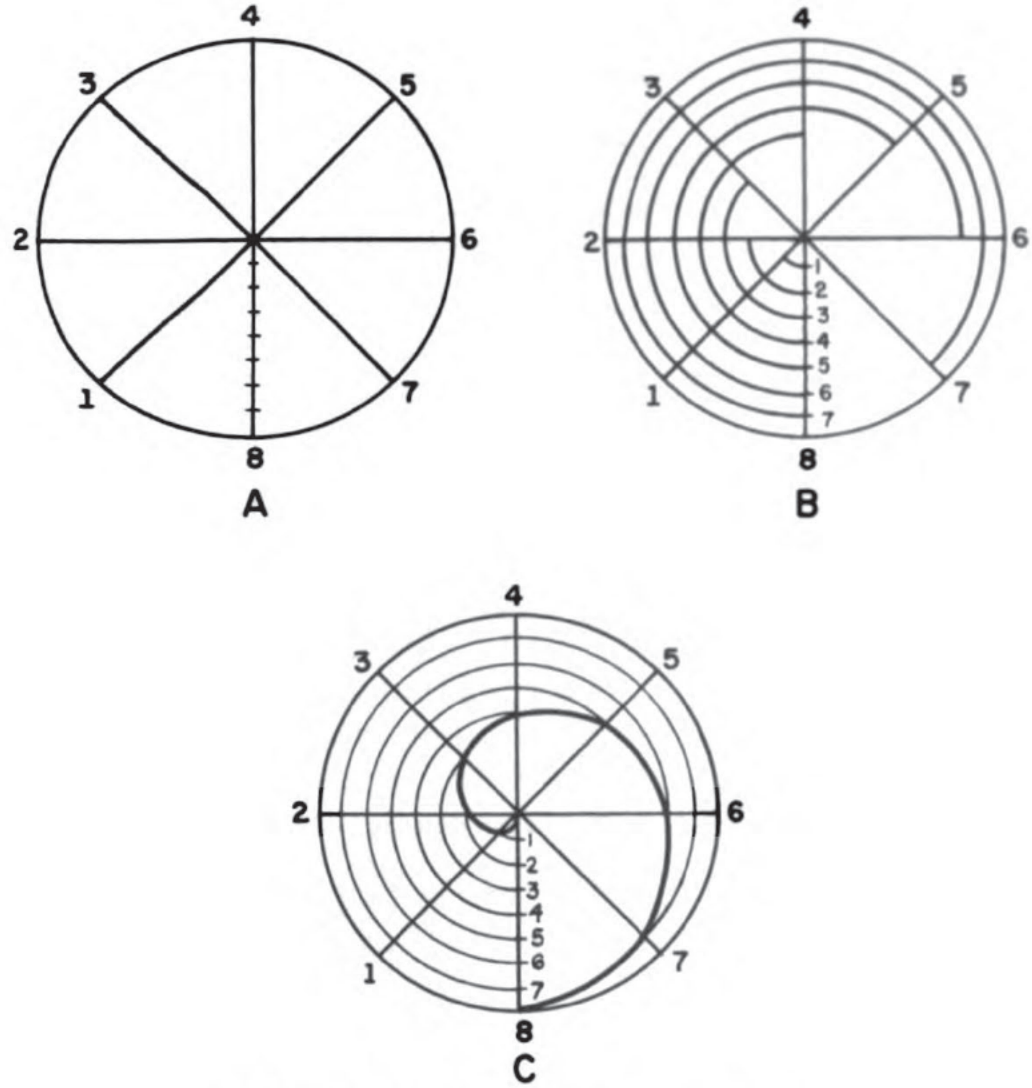


Figure 4–30.—Method of drawing a spiral.

HELIX.—The helix is a curve in space which is generated by a point moving uniformly along a straight line which revolves around an axis. If the line moves parallel to the axis, it will generate a cylindrical helix. If it moves at an angle to the axis, it will generate a conical helix. The LEAD of a helix is the distance parallel with the axis which the point advances along the line in one revolution.

To draw a helix, draw two views of the cylinder, as shown in figure 4–31A. Divide the lead into an equal number of parts and the diameter into the same number of parts, as

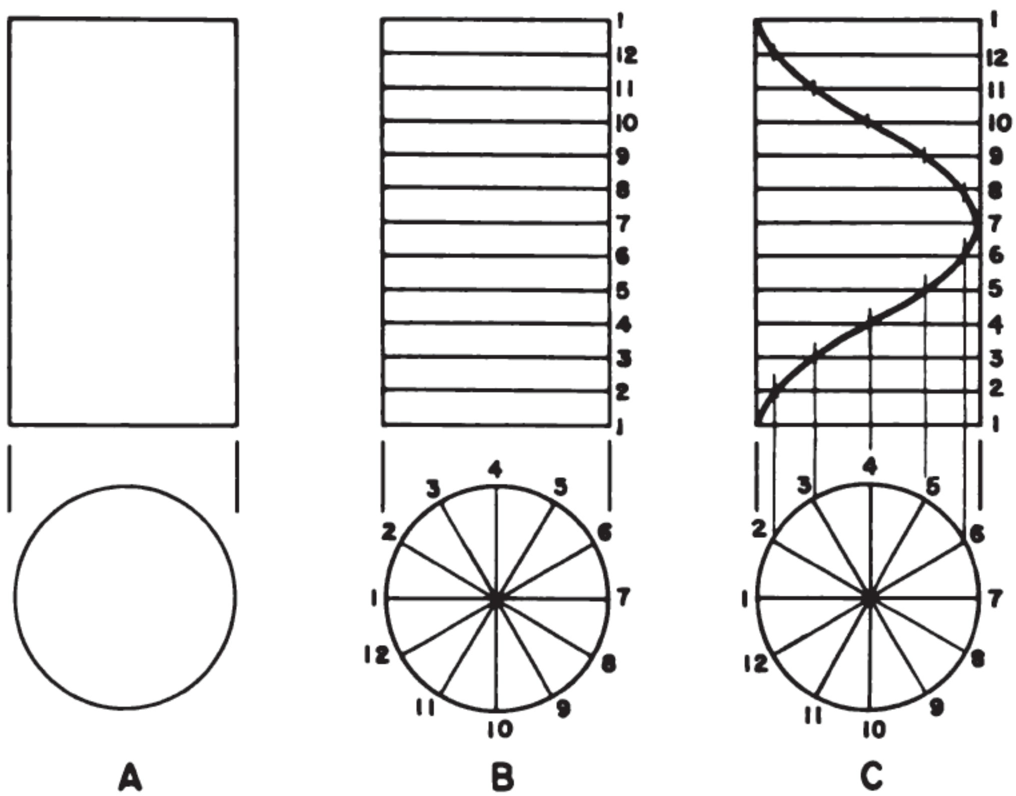


Figure 4–31.—Method of drawing a helix.

shown in figure 4–31B. The intersection of the lines from these points, as shown in figure 4–31C, are the points of the cylindrical helix.

LOGARITHMS

Chapter 9 in NavPers 10070–A discusses logarithms, one of the most useful of mathematical processes to the man who must work with large numbers. The logarithm of a given number is the exponent indicating the power to which another number called the base must be raised to produce the given number. Logarithms are useful because, like other exponents, they are added in problems of multiplication and subtracted in problems of division, thereby shortening the arithmetical processes involved and so simplifying them that there is less chance of errors.

In NavPers 10070–A, the chapter on logarithms is introduced by a test and a discussion of powers and roots since logarithms are exponents and must be used like other ex-

ponents. If you can pass this test, skip the section following it and take test 10 on page 160 on logarithms themselves.

There are two systems of logarithms in use. That is, there are two different bases used. One base is 10, and this is always the base in the system called COMMON LOGARITHMS. The other base, 2.7182818+, is used in the system called NATURAL or NAPERIAN LOGARITHMS. Naperian logarithms are used in pure mathematical discussion and in advanced engineering. In this section, common logarithms, which are in general use, will be discussed.

It is apparent that the logarithm of 100, 1,000, or any other integral power of 10 is simply equal to the number of times that 10 is multiplied by itself to give the number. But in order to find a logarithm of a number that is not an integral power of 10, you will have to find a logarithm between 0 and 1 or 1 and 2 or 2 and 3 which will contain a fraction usually expressed as a decimal. Therefore, the logarithm of a number is composed of an integral portion to the left of the decimal, called the CHARACTERISTIC, and of a decimal fraction, called the MANTISSA.

A number between 1 and 10 will have a logarithm that is more than 0 but less than 1. The characteristic of such a number will be 0. When the number is between 10 and 100, the characteristic will be 1. In the same way, the characteristic of a number between 100 and 1,000 will be 2. It may help you to remember that the characteristic of the logarithm of a given number is always a quantity one less than the number of places to the left of the decimal place in the number.

Since the characteristic of a logarithm can be arrived at in this manner, the mantissa of a logarithm is all that appears in a table of logarithms. The degree of accuracy of this mantissa depends on the number of decimal places used. The table of logarithms included in NavPers 10070–A is to four decimal places. It is compact and convenient, but where greater accuracy is desired, a table of five or more decimal places is recommended.

Interpolation is a process which is used in a great many different mathematical areas. It is a method for finding an unknown number which falls between two other known numbers. Suppose you want to find the logarithm of 14.15. You know that the characteristic is 1. When you look at the table to find the mantissa, 14.15 cannot be found, and the nearest numbers in the table are 141 and 142. These numbers may be used to compute the mantissa of 14.15. Thus

$$\begin{aligned}
\text{Log } 14.1 &= 1.1492 \\
\text{Log } 14.15 &= ? \\
\text{Log } 14.2 &= 1.1523 \\
\text{Tabular difference} &= .1523 - .1492 = .0031 \\
\text{One half tabular difference} &= .5 \quad \times .0031 = .00155 \\
&= .0016 \text{ (rounded off)} \\
\text{Therefore, log } 14.15 &= 1.1492 + .0016 = 1.1508.
\end{aligned}$$

This figure is not exact, but for all practical purposes, it will serve. Some tables include a proportional part (P. P.) column in which the logarithm for an extra place in a number can be found.

An antilogarithm may also be found when the known logarithm contains a mantissa which falls between two other mantissas in the table. For example, find the antilogarithm of 2.5484. In the table, the next smaller mantissa is .5478 and the next higher is .5490.

$$\begin{aligned}
\text{Log } 353 &= 2.5478. \\
\text{Log } x &= 2.5484. \\
\text{Log } 354 &= 2.5490.
\end{aligned}$$

The difference between log 353 and log $x = .0006$. The tabular difference between log 353 and log $354 = .0012$. Since the increase of .0012 corresponds to an increase of 1 between 353 and 354, we can assume that the increase of x is equal to the fraction $\frac{.0006}{.0012} = \frac{1}{2} = .5$. Therefore, $x = 353.5$.

Naturally, most of the problems involving interpolation will not work out so neatly with the fraction ½. You may

have odd fractions, and sometimes it will be convenient to take the nearest decimal equivalent, thereby reducing the accuracy of your solution slightly.

SLIDE RULE

The use of the C and D scales of the slide rule is discussed in Chapter 4, *Draftsman 3*, NavPers 10471. In order to understand the working principle of these scales and of other scales on the slide rule, you should realize that the gradations on the scales are really the logarithms of the numbers. Figure 4–32 shows the relationship between a number scale and logarithm scale.

Figure 4–32.—Comparison of number and logarithm scales.

Actually when you use a slide rule, you are adding or subtracting the logarithms of numbers, just as exponents are always added in problems of multiplication and subtracted in problems of division. Two ordinary equal-parts scales can be manipulated like the slide rule to add or subtract numbers, but not to multiply or divide them. In figure 4–33, when the 0 of the upper scale falls over 3, you can add 3 to any number on the upper scale to get the number under it. When 3 is added to 3, the sum is 6 which is the number on the lower scale under 3. In the same way, when the number on the upper scale is subtracted from the number under it on the lower scale, the quotient will be found under the zero on the upper scale.

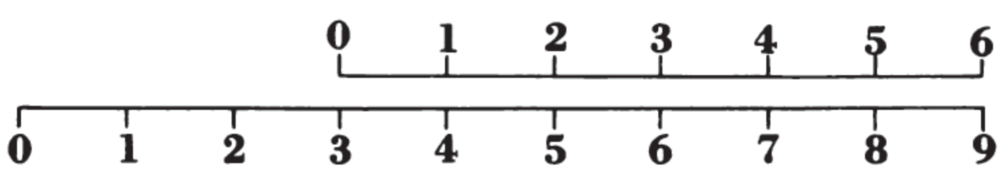


Figure 4–33.—Equal-parts scales may be used for addition and subtraction.

In the same way, the C and D scales are used to add logarithms, as demonstrated in figure 4–34. If the left index on C is placed over 2 on D, the 4 on C is over 8.

$$
\begin{aligned}
\text{Log } 2 &= .301 \\
\text{Log } 4 &= \underline{.602} \\
\text{Sum} &= .903 \\
\text{Antilog } .903 &= 8.
\end{aligned}
$$

In this section only the A, B, and K scales, which are used to find the squares and cubes and the square roots and cube roots of numbers, will be discussed. The A and B scales

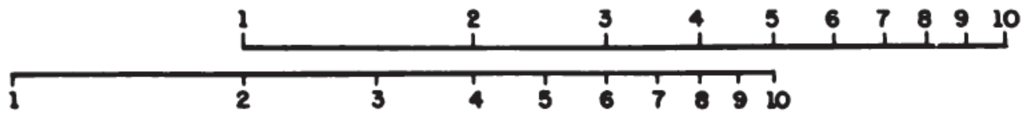


Figure 4–34.—Logarithm scales may be used for adding or subtracting logarithms, which is the same as multiplying or dividing numbers.

may also be used for multiplication and division and for problems involving the diameter and area or the diameter and circumference of circles. Some slide rules also contain inverted scales labeled CI and CIF, an L scale, and S and T scales. The CI or CIF scales may be used to find reciprocals and for compound multiplication problems. The L scale is used to find the logarithm of a number. The S and T scales are used to read trigonometric functions. For descriptions of the use of these scales, obtain a copy of EM 960, *A Course in the Slide Rulc and Logarithms*, through your Information and Education Officer.

The numbers on the A and B scales are the squares of those on the C and D scales, while the numbers on the K scales are the cubes of those on C and D. Notice that the A scale is really 2 small D scales and that the K scale is 3 small D scales. This doubling and tripling of scales has the effect of doubling and tripling logarithms. (See fig. 4–35.)

To find the square of a number, place the hairline on the indicator over the number on the D scale and read the square on the A scale. If you are using the C scale, read the square

on the B scale. In the same way, if you have a slide rule with the K scale on it, you can place the indicator over a number on the D scale and read the cube on the K scale.

For example, find the square of 6. First, place the indicator with its hairline over the 6 on the D scale. Then read 36 on the A scale. Since the square of 6 must be a 2-

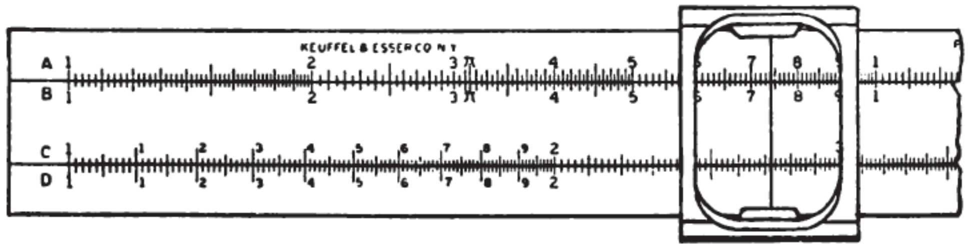


Figure 4–35.—Portion of a slide rule showing the A, B, C, and D scales.

digit number, 36 is read and not 3.6. It is very much like placing the decimal in slide-rule problems involving decimals. You must use common sense.

One way to read the square correctly is to remember that a number on the left side of the scale will have an uneven number of digits to the left of the decimal point, while one on the right side will have an even number. For example, the square of 12 is 144 and falls on the left side; the square of 8 is 64 and falls on the right side. If the number to be squared is a decimal fraction and its square falls on the left side of the A scales, there are an odd number of zeros between the decimal point and the first digit of the decimal. For example, if the decimal to be squared is .02, the square falls on the left half of the scale and will be .0004. If the square of a decimal falls on the right half of the scale, there are no zeros or an even number of zeros between the decimal point and the first digit of the number. If the decimal to be squared is .04, the square falls on the right half of the scale, and reads .0016 with an even number of zeros.

You can work out a key for reading the indexes. For example, if the number to be squared is 6, the key is 1. If the number to be squared is 12, the key is 10. If the key is 1, then the numbers between the left index and the middle index

will run from 1 to 10, and those between the middle index and the right index from 10 to 100. If the key is 10, the left index will be 100, the middle index 1,000, and the right index 10,000. Study the following table for other keys and index values.

Key	A indexes			K indexes			
	Left	Middle	Right	Left	First middle	Second middle	Right
0.01	0.0001	0.001	0.01				
0.1	0.01	0.1	1	0.001	0.01	0.1	1
1	1	10	100	1	10	100	1,000
10	100	1,000	10,000	1,000	10,000	100,000	1,000,000

To find the square root of a number, place the indicator over the number on the A scale and read the root under the indicator on the D scale. The B and C scales may be used instead of the A and D scales if they are more convenient.

In finding square roots on the slide rule, you will find that your chief problem consists of setting the indicator to the number on the proper section of the A or B scale. The following rules will help you determine on which section of the scale to set the indicator:

1. IF THERE ARE AN ODD NUMBER OF DIGITS TO THE LEFT OF THE DECIMAL IN THE NUMBER, THE INDICATOR SHOULD FALL ON THE LEFT SCALE. For example, 9 is found on the left side of the A scale, and the square root 3 is read below it on the D scale.
2. IF THERE ARE AN ODD NUMBER OF DIGITS FROM THE FIRST SIGNIFICANT FIGURE IN A DECIMAL FRACTION, THE INDICATOR SHOULD FALL ON THE LEFT SIDE OF THE SCALE. For example, .09 falls on the left side and the root .03 is read below it.
3. IF THERE ARE AN EVEN NUMBER OF DIGITS TO THE LEFT OF THE DECIMAL IN THE NUMBER, THE INDICATOR SHOULD FALL ON THE RIGHT SCALE. For example, 64 is found on the right side of the A scale and 8 is read below it on the D scale.

4. IF THERE IS AN EVEN NUMBER OF DIGITS FROM THE FIRST SIGNIFICANT FIGURE IN THE DECIMAL FRACTION, THE INDICATOR SHOULD FALL ON THE RIGHT SCALE. For example, .064 is found on the right side of the A scale and .08 is read below it on the D scale.

The position of the decimal point in a root may be determined by dividing the number into periods of two digits each, starting from the decimal point and working to the right and then to the left. In each case, the final period may consist of only one digit. The root will have the same number of digits on either side of the decimal point as the number of periods marked off. For example, to find the square root of 158.76, divide the number into periods thus, 1′58.76. Then read the root as 12.6. The square root of .00576, which is marked off thus, .00′57′6, is .024 and not .0024.

To find the cube root of a number, find the number on K and read the root on D.

In using the K scale, you have three sections from which to choose when you set the scale to read a cube root. The simplest way to find the correct setting is to count the digits left from the decimal point thus: 1, 2, 3, 1, 2, 3, etc. If the last digit to the left falls on the count 1, use the first or left section of the K scale. If it falls on 3, use the third or right-hand section. For example, you would find the number 9261 on the left section, the number 64 on the center section, and the number 512 on the right section of the scale.

QUIZ

1. **What is the smallest number of straight lines that can be used to bound a plane figure?**
2. **On what fact concerning triangles is trigonometry based?**
3. **What are the tabulated ratios for the sides of right triangles called?**
4. **Why is the sine of an angle in the second quadrant positive?**

5. Although the signs of some of the functions differ, an angle of 284° in the fourth quadrant has the same functions as what angle in the first quadrant?
6. What is the point of intersection of the axes called?
7. What are the four parts called into which a graph is divided by the axes?
8. (a) When both coordinates of a point are given, which is given first? (b) On which axis is its value found?
9. What curves are called conics and why?
10. What is the definition of a parabola?
11. How is a hyperbola generated?
12. (a) How is a cycloid generated? (b) An epicycloid? (c) A hypercycloid?
13. What is a helix?
14. What is the lead of a helix?
15. Why are logarithms useful?
16. What base is used in the system of common logarithms?
17. What does the characteristic of a logarithm of a given number indicate?
18. What is an antilogarithm?
19. What are the A and B scales on the slide rule used for?
20. Using the A and D scales, what steps would you take in order to find the square of a number?
21. What steps are necessary in order to find the square root of a number?
22. In finding a square root, if there are an odd number of digits to the left of the decimal in a number or an odd number of digits from the first significant figure in a decimal fraction, you should set the indicator on which section of the A or B scale?
23. In using the K scale to find a cube root, if the last digit to the left from the decimal in a number falls on count one, you should set the indicator on which section of the K scale?

CHAPTER 5

MACHINE PARTS

MACHINE DRAWINGS

When a complex piece of machinery is to be made, whether it will be produced as a single unit or in quantity, the problems involved in producing it are worked out on the drawing board. First, a design drawing is made by an engineer, engineer officer, or a well-trained and experienced draftsman working from sketches made by an engineer. Then detail drawings of each part are made from this design drawing. Finally, an assembly drawing is drawn to show how the machine is assembled. Often a mistake in a detail drawing shows up on the assembly drawing which, therefore, also serves as a check on the earlier work.

The detail drawings and assembly drawings of a machine comprise the working drawings, from which the machine is made, as distinct from the design drawing or such drawings as display drawings intended for other purposes. The working drawings of a piece of machinery tell what manufacturing processes and materials are used, and how the different parts are finished, as well as the dimensions of the parts.

The draftsman making detail or assembly drawings should know something about materials, how they are produced, and what the different terms used in connection with them mean. He should also have an acquaintance with machine shop work and the fabrication of metal and plastic products.

METALS

Metals are divided into two general types—ferrous and nonferrous. Ferrous metals are those whose major pro-

portion is iron. Iron is the basis for all steels. Nonferrous metals are those whose major proportions are not iron, although they may contain a small amount of iron as an impurity.

Iron

The main source of all ferrous metals is, of course, iron ore, which is an iron oxide containing varying amounts of impurities. In order to extract iron, the ore is heated in a blast furnace in contact with other elements which have a greater binding power for oxygen than does the iron. The blast furnace is operated continuously, and the melted iron and slag which collect at the bottom are drawn off at regular intervals. The molten metal from the blast furnace may be further refined before it is allowed to cool, or it may be cast into shapes of approximately 80 pounds which are called PIGS. In either case the product of the blast furnace is called PIG IRON.

PIG IRON is composed of approximately 93 percent iron, 3 to 5 percent carbon, and varying amounts of other elements. Pig iron is remelted with certain proportions of scrap to provide the desired chemical properties of iron for the manufacture of CAST IRON. Because of its brittleness and low tensile strength, cast iron is limited in use.

When pig iron is further refined through a process known as puddling, WROUGHT IRON is obtained. This iron is used in the manufacture of pipes, nails, and rivets. It is workable and has a fibrous internal structure due to the rolling and squeezing given to it when it is being made. Wrought iron and mild steel are very much the same in chemical content, but they exhibit different physical properties because of the different manufacturing processes involved.

Steel

Steel is made from molten iron from the blast furnace or from remelted pig iron by bringing it into contact with a liberal supply of oxygen which consumes the excess carbon and

some other impurities. Most steel is produced by either the open hearth or the bessemer process. High grade steel in small quantities can be produced in an electric arc furnace. However, this process is most costly. Sometimes carbon is simply added to wrought iron to produce steel in what is called the crucible process.

Actually the name STEEL is applied to a number of mixtures containing radically varying ingredients and properties. Carbon and iron are present in all steels. Carbon steel with a carbon content up to 0.75 percent can be cut, shaped, and welded. When the carbon content of the steel is above 0.75 percent, it can be readily hardened.

Alloying elements are also added to steel to produce desired qualities. Such elements are important in tool steel, especially the so-called high-speed steels, which are used for the tools that cut other metals at high speeds. Alloy steels often bear names which indicate the important elements responsible for their particular properties.

Nonferrous Metals

One of the most important nonferrous metals is COPPER. Like the ores of iron and all other base metals, copper ore must be mined, smelted, refined, and then rolled to the desired shape. In comparison with iron, copper is a rare metal. There is much less copper in a ton of copper ore than there is iron in a ton of iron ore, and the process for extracting copper from the ore and refining it is much more expensive than that for iron.

COPPER is an excellent conductor of electricity and has excellent resistance to salt-water corrosion. It becomes hard when worked but is easily softened by heating. Copper seams may be joined by riveting, soldering, or brazing, or by using standard sheet-metal seaming procedures.

ZINC is used as an alloying ingredient in making brass and some bronzes. It is also often used as a protective coating on steel sheets, which are then called galvanized sheets. Pure zinc plates, called zinc protectors, are used to protect

hulls and hull fittings from galvanic or battery action. These zinc protectors are installed on hulls of all steel ships and also in machinery through which salt water must circulate. Zinc is also used for batteries, jar tops, and lithographic plates.

TIN is seldom used except as an alloying ingredient. Alloyed with lead, it makes a soft solder, and alloyed with copper, it produces bronze. Lead and tin both resist corrosion, but tin has the added advantage of being nonpoisonous. For this reason, cans for food are fabricated from sheet metal which has been coated with tin.

ALUMINUM is being used more and more because of its light weight, easy workability, good appearance, high resistance to corrosion, and other desirable properties. Pure aluminum is soft and not very strong. When alloying elements such as magnesium, copper, nickel, and silicon are added, however, an alloy stronger than low carbon steel can be produced. Duralumin was one of the first of such alloys. The subject of aluminum and its alloys and systems of numbering will be covered more fully in chapter 9, "Aeronautical Drafting."

NICKEL is a hard, malleable, and ductile metal. It is resistant to corrosion and is therefore often used as a coating on other metals. Combined with other metals, its effect is to make the alloy hard, strong, and ductile. It also imparts greater resistance to oxidation and corrosion.

True BRASS is an alloy of copper and zinc. Complex brasses are those containing additional alloying agents, such as aluminum, lead, iron, manganese, or phosphorus. Naval rolled brass is a true brass containing about 60 percent copper and 40 percent zinc. It has a high resistance to corrosion. Brass comes in sheets, strips, bars, and wire spring, or it may be used for castings.

BRONZE made of 84 percent copper and 16 percent tin was the best metal available for a great many uses before steelmaking techniques were developed. The first good naval cannon was made of bronze about 500 years ago. Although bronze was originally an alloy of copper and tin, many com-

plex bronze alloys containing three or more elements have been developed. Therefore, there is now no distinct line between brass and bronze. In fact, commercial bronze which is used for hinges and other hardware is really a brass containing 90 to 95 percent copper and 5 to 10 percent zinc.

COPPER-NICKEL alloy is found extensively aboard ship because of its high resistance to the corrosive effect of salt water. It is used in piping and tubing, and in sheet form, it is used to construct small storage tanks and hot-water reservoirs. Copper-nickel alloy contains 70 percent copper and 30 percent nickel. It has the general working characteristics of copper, but it must be worked cold. Copper nickel is best jointed by the silver-brazing process.

MONEL contains from 64 to 68 percent nickel, about 30 percent copper, and small percentages of iron, manganese, and cobalt. In appearance, monel resembles stainless steel. In fact, it has many of the qualities of stainless steel. It is harder and stronger than either nickel or copper, but it can be easily worked. It has a very high resistance to corrosion, and is so strong that it may be substituted for steel where corrosion resistance is of primary importance. These qualities make it valuable for use in pump parts, turbine blades, laundry equipment, steam valves, head fixtures and equipment, nuts, bolts, screws, and control parts.

K-MONEL is a special improved type of alloy that is stronger and harder than ordinary monel. Its strength is comparable to that of heat-treated steels. It is used for instrument parts that must resist corrosion.

INCONEL is a nickel alloy containing 78 percent nickel, 14 percent chromium, 6½ percent iron, and about 1 percent other elements. It has great resistance to corrosion and retains its strength at high temperatures. Exhaust systems of engines are often made of inconel.

Hardness Tests

The hardness of a substance may be defined as its resistance to penetration by another substance. Many methods

have been devised for measuring hardness of metals. Sometimes they are tested by filing. If the file bites with great ease into the metal, it is very soft. If the file slides over the metal and its teeth become dull, the metal is extremely hard. In between these two extremes are soft, medium, and hard metals. The accuracy of the file test depends to a large extent upon the skill of the man using the file.

However, the degree of hardness of the metal may be specified according to the number scales of special hardness tests, such as the Rockwell, Shore's Scleroscope, or Brinell. The Rockwell Hardness Test is based on direct measurements of the indentation in a piece of metal which is made by a spherical point of a given size and under given pressure. The reading is taken from a graduated dial on the face of the machine. The B scale is used for metals of average hardness and utilizes a point $1/16$ of an inch in diameter and a load of 100 Kg. The C scale is used for harder metals and a 120-degree conical diamond point is used with a load of 150 Kg. For example, R_c 44–48 means that the hardness of the metal part is between 44 and 48 on the C scale of the Rockwell Hardness Test.

Heat Treatment

Cutting tools, chisels, twist drills, and many other pieces of equipment and tools must be hardened to enable them to retain their cutting edge. Surfaces of roller bearings, parallel blocks, and anvils must be hardened to prevent wear or penetration.

Metals are heat treated to produce changes in their structure and physical properties. These changes are produced by variations and (1) the temperature to which the metal is heated, (2) the rate of heating, (3) the time the metal is kept at the correct or critical temperature, (4) the furnace atmosphere, and (5) the cooling process and medium. There are several forms of heat treating. The most common for ferrous metals are annealing, normalizing, and hardening, which includes tempering and case-hardening.

The purposes of ANNEALING are to induce softness, reduce stresses, change the ductility, or improve the grain structure of metals which may have been impaired by unequal heating or by machining processes. Annealing is accomplished by heating the metal to a point above the critical temperature, holding it at this temperature until the grain structure has been refined, and then uniformly cooling it under controlled conditions. Annealing is often used for softening nonferrous alloys and pure metals after they have been hardened by cold work. Some of these alloys require annealing operations which are different from those for steel. For example, duralumin is heated to 986° F. and then cooled very rapidly by quenching in water. It is workable for about 45 minutes, after which time it becomes hard again. Copper may also be annealed by quenching.

NORMALIZING is a process very similar to annealing, but it is done for different reasons. Normalizing is done to improve and equalize the grain structures of forgings and castings that contain stresses and strains caused by forging work, uneven cooling of castings, or other reasons. The metal is heated to from 50° to 100° above its normal hardening temperatures and allowed to cool evenly in air.

HARDENING of metals and alloys is done in several ways. To harden steel, it is heated to a little more than the critical temperature. Then it is cooled rapidly by being quenched in oil, fresh water, or brine. The most commonly used quenching medium is fresh water, but it is sometimes necessary to use oil for high carbon and alloy steels to prevent too rapid quenching, which would result in warping and cracking. This hardening operation gives the steel a fine grain structure, extreme hardness, greater tensile strength, and less ductility. In this condition, steel is sometimes harder than necessary and is generally too brittle for most practical uses.

Tempering, a process which follows hardening, is generally applied to steel to relieve the strains that are brought about during the hardening process. Tempering is done by heat-

ing the hardened steel to a temperature below the critical range, holding this temperature for sufficient time for it to completely penetrate the piece, and then cooling in water, oil, or air.

Case-hardening is another hardening process of heat treating, by which the outer surface of a piece of metal is hardened, leaving the inner part relatively soft and tough. This is usually done by using metal that is originally low in carbon and adding carbon to the outer surface by various means and then hardening. Carbon is usually added by packing the metal in a substance high in carbon content and heating the metal above the critical range. The length of time the piece is left in the oven at this temperature determines the depth to which carbon is absorbed. After it has been in the oven the proper length of time, it is allowed to cool slowly to room temperature. The part is then hardened in the same manner as carbon tool steel.

Cyaniding is the term applied to the superficial case-hardening process in which steel, when heated to the proper temperature, absorbs a combination of nitrogen and carbon. The cyanide compound now used is a mixture of sodium cyanide and sodium chloride. It gives best results when used in a bath.

Nitriding is a case-hardening process that has been developed in recent years. This method requires a special steel—nitralloy—designed to absorb nitrogen. Elaborate treating equipment is required, and the process is more expensive than carburizing or cyaniding.

On the drawing, the heat treatment for a part may be indicated in several ways. A general note may list the steps, temperatures, etc. A hardness-test number or the tensile strength (psi) required for the part may be given.

PLASTICS

Although the use of plastics is relatively new, it will be increasingly important in the future. Plastics are generally considered to be organic compounds that are capable of being

formed or molded. They have been designed to perform particular functions that no natural material can attempt to equal. They can be obtained in all varieties of color and form. Some are more transparent than glass. Some are as tough, but not as hard, as steel. Some are as pliable as rubber. Some are lighter than aluminum. They are generally classified as thermoplastic or thermosetting.

Thermosettings are plastics which must be heated to be hardened. They are sometimes referred to as heat-hardened. They are very hard, tough, and brittle. Whenever thermosettings are placed in a flame, they will not burn readily, if at all. If the plastic is immersed in hot water and allowed to sit, the plastic will neither soften nor absorb moisture.

Thermoplastics require no heat to harden. In fact, when heat is applied to them, they will either melt or become soft and pliable. When they are immersed in hot water and allowed to sit, they will soon become sufficiently soft and pliable to bend and, when they are cooled, will retain whatever shape they may have been given. Some thermoplastics may even absorb a certain small portion of the moisture.

In the Navy, the following groups of plastics are most commonly used: phenol-formaldehyde plastics, commonly called phenolics; polymethyl methacrylate, called acrylics; polystyrene, called styrene; cellulose acetate plastics, called acetate; and laminated plastics.

PHENOLICS are thermosetting plastics, and they are molded into such shapes as pump impellers, control wheels, utility boxes, telephone handsets, bayonet handles, and some electrical fittings. They are reproduced in steel molds, are smooth in appearance, and have excellent mechanical durability. Once hardened, or cured, phenolics cannot be softened again to any appreciable extent, since they are thermosettings. Some of the familiar names found in the molded phenolics are Bakelits, Durez, Plastone, and Uniplast.

The ACRYLICS, STYRENES, and ACETATES are identical in appearance, and all three are thermoplastics. This, however, is as far as their mutual attributes go.

Acrylics are thermoplastic materials, which may be softened an infinite number of times by the application of heat. Besides the unusual clarity of the acrylic sheets, a good dimensional stability and the ability to withstand sunlight are inherent factors. Acrylics are available in rods, sheets, and tubes, as well as molding powders from which crystal-clear products may be produced. Acrylic plastics are especially valuable for making cockpit and gun-turret enclosures for planes. Compared to glass, acrylics still have one serious drawback—they are scratched more easily.

Styrene, another transparent material, exhibits some of the most outstanding properties of all plastic materials, including excellent chemical resistance, low specific gravity, good electrical properties, and low water absorption.

Cellulose acetate is developed in three chief grades for use as films, plastic articles, and lacquers. The plastic grade is readily compounded into molding powders and into miscellaneous sheets, rods, and tubes. It is cheaper than acrylic plastic for transparent enclosures but discolors with age and is less durable.

LAMINATED PLASTICS are made by dipping, spraying, or brushing flat sheets, or continuous rolls, of paper, fabric, or wood veneer with resins, then pressing several layers together to obtain hard, rigid structural material. The number of layers pressed together into one sheet of laminated plastic will depend upon the thickness of the sheet desired. The choice of paper, canvas, wood veneer, or glass fabric will depend upon the end use of the product. Paper-base material is thin and quite brittle. It will break if you bend it sharply, but the canvas-base material will be difficult to break. Paper-base material gains strength through a greater number of layers but is never as tough and strong as layers of glass fabric or canvas in a laminated part.

Laminated phenolics are used in many ways aboard ship. For example, laminated gears are found on internal combustion engines, usually as timing for idler gears, on laundry equipment, and on certain pumps. In comparison with metal

gears, plastic gears are much quieter in operation, pick up less heat when friction is established, and wear longer.

The Navy has now developed methods of molding laminated plastic articles of considerable size. Among these are plastic boats. These boats are light in weight, moisture-proof, strong, and can be produced from readily obtainable materials at a tremendous saving in man-hours.

PRODUCTION OF METAL PRODUCTS

Most metal products are produced by either casting, forging, or fabrication of rolled shapes. For articles that require a high finish or close dimensional tolerances, these processes are followed by machining. Some of the newer processes in manufacturing metal products are die casting and sintering, but these are rarely used in the Navy.

Casting

Casting is that process in which metal is melted and poured into molds where it is allowed to cool and harden, resulting in a metal product of specified size and shape. (See fig. 5–1.) Molds are usually made of sand with a small amount of some cohesive material mixed in. The molds are shaped by packing the sand around a pattern made either of wood or metal. In the cooling process, there is a great deal of shrinkage of the metal, and this must be allowed for by the patternmaker. Also, in order for the metal part to be removed from the mold after the metal has hardened, the sides of the pattern must be made with a draft, which means that they taper. For a better understanding of this work, read *Patternmaker 1 and C*, NavPers 10579.

A detail drawing of a part to be cast may merely show the dimensions of the finished piece, and the shrinkage and draft may or may not be indicated in notes, depending on local practices. On the other hand, a separate detail drawing may be made showing the draft and giving only those dimensions needed by the patternmaker. In this case, both the

Figure 5–1.—Pouring liquid metal into the mold.

drawing of the cast part and of the finished part may be included on one sheet for use first by the patternmaker and then by the machinist, or they may be drawn on separate sheets.

Rolling

Rolled steel comes in a great variety of shapes and in practically any length that can be shipped. When steel intended for rolling comes from the furnace, it is cast into INGOTS; that is, pieces of suitable shape and size for the rolling mill to handle. After a process of controlled cooling, called soaking or seasoning, and perhaps reheating, the rolling process is begun. Each time the ingot passes through the rolls, it comes out a little longer and a little nearer to the desired shape and size. Machine parts are often made of cold-rolled steel or cold-drawn steel on which the final shaping is done after the metal cools. The cold working gives the steel extra toughness and other desired qualities.

Forging

Forging is perhaps the oldest method of working metal. This simply means that the metal is hammered into the desired shape after it has been heated to a plastic state. (See fig. 5–2.) Forging may be done by hand or by power hammer, or a part may be drop forged, which means that the plastic metal is shaped by pressure between forming dies.

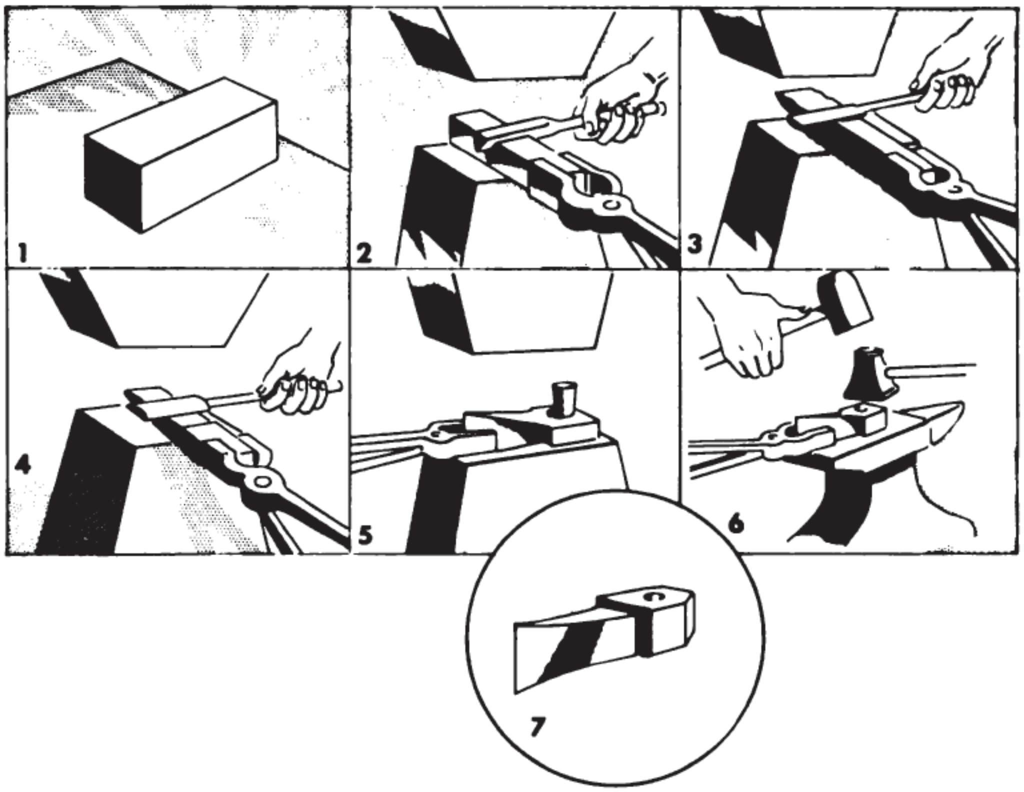


Figure 5–2.—Forging a hot cutter.

Extruding

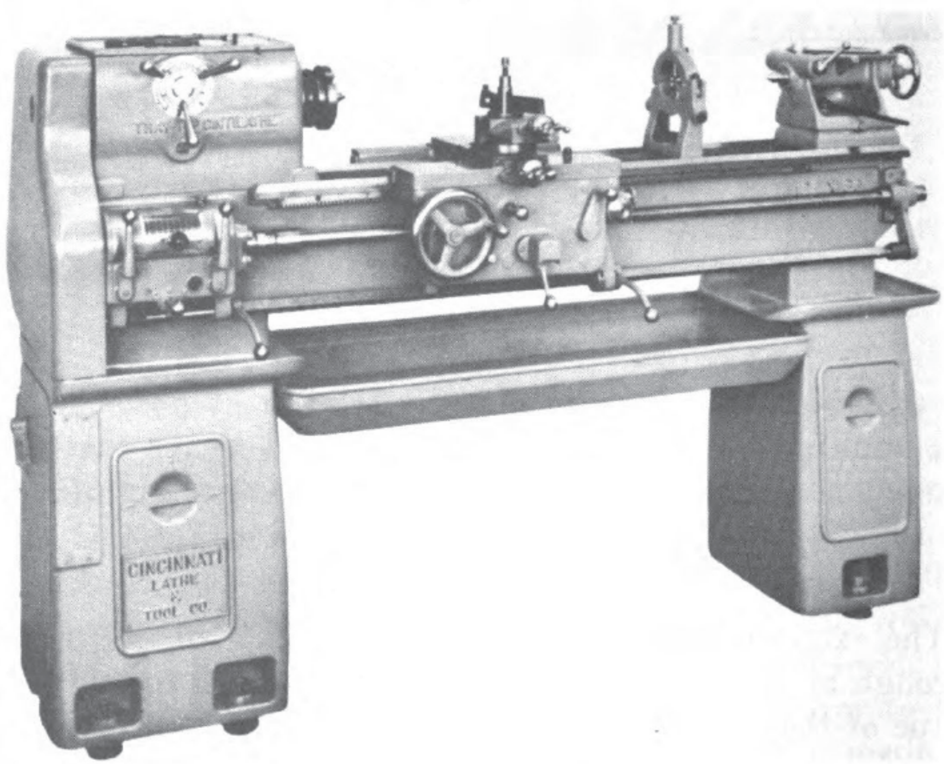
The extrusion process involves the forcing of hot metal through an opening in a die, causing the metal to take the shape of the die. A cylinder of aluminum, for instance, is heated to around 750° to 850° F. and is then forced through the opening of a die by a hydraulic ram. Some of the softer metals may be extruded cold, but generally metals are heated

before the operation is begun. Many aircraft structural members are formed by the extrusion process.

Machine Shop Work

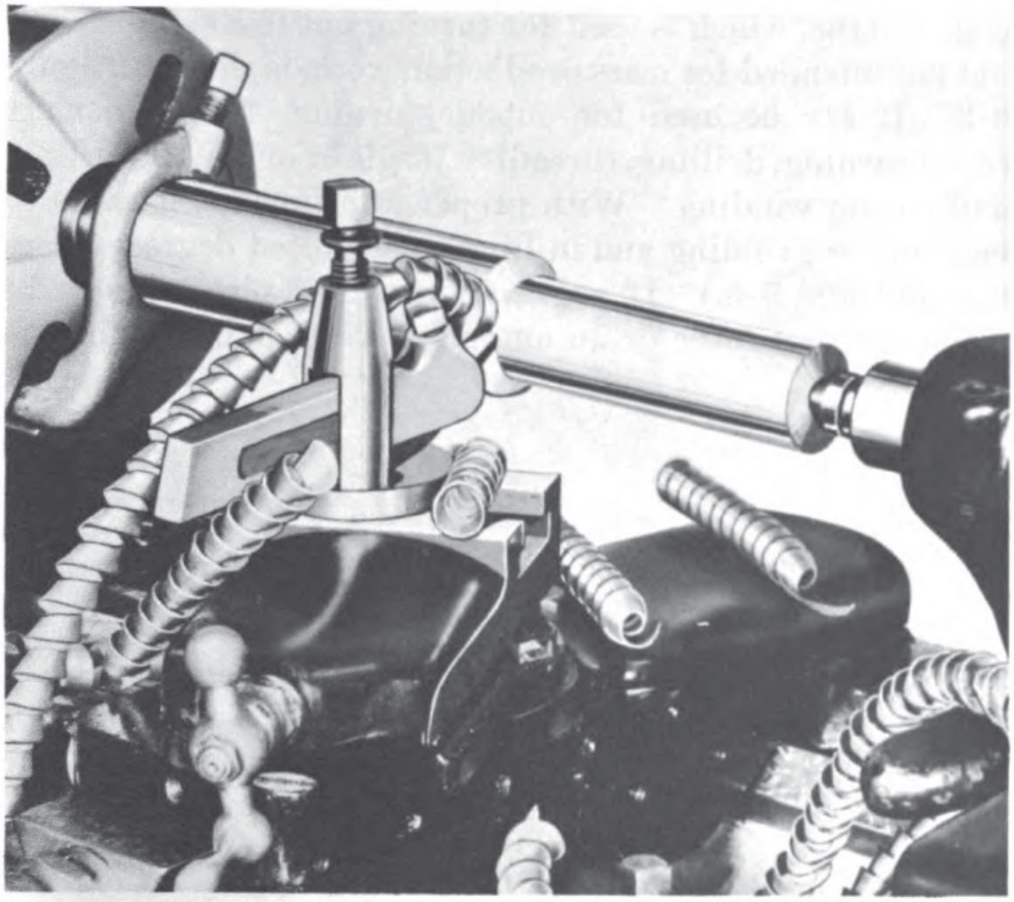
Machine finishing may be done by either cutting or grinding the metal away. Grinding produces a smoother surface and is usually used only after a cutting process. In the past, parts produced by mass production had to be matched with each other for proper fit at assembly. The mass production of machine parts can now be held within .001 in accuracy, or even closer if necessary. Thus, a repair part for any machine fits and operates just as well as the original part.

The most common cutting operations consists of TURNING, PLANING, MILLING, and DRILLING. For turning, which includes the forming of surfaces such as cylinders, cones, and screw threads, the lathe or the boring machine is used. An



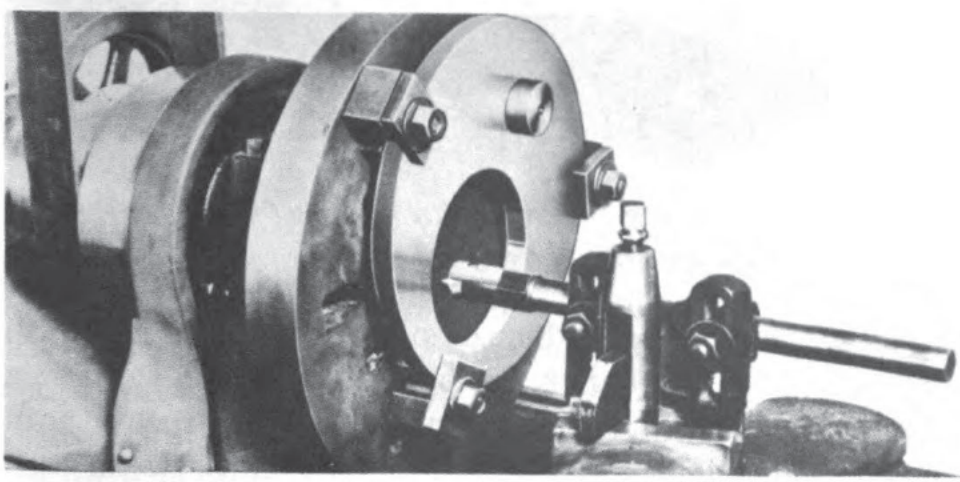
Courtesy Cincinnati Lathe & Tool Co.

Figure 5–3.—An engine lathe.



Courtesy South Bend Lathe Works

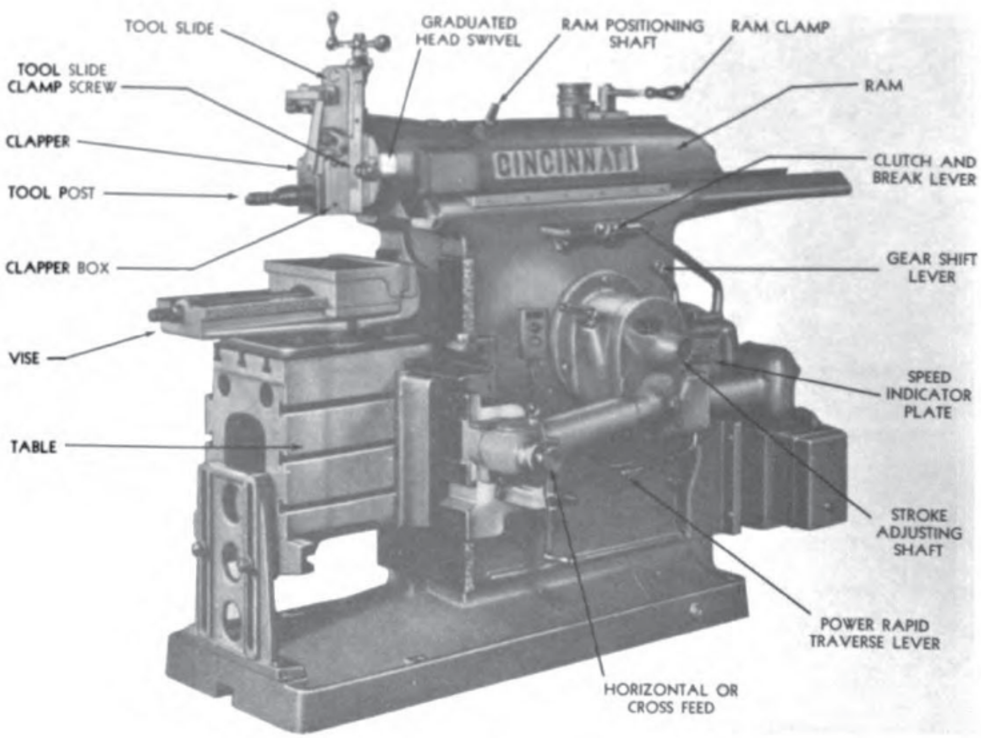
Figure 5–4.—A rough turning.



Courtesy South Bend Lathe Works

Figure 5–5.—Boring an eccentric hole.

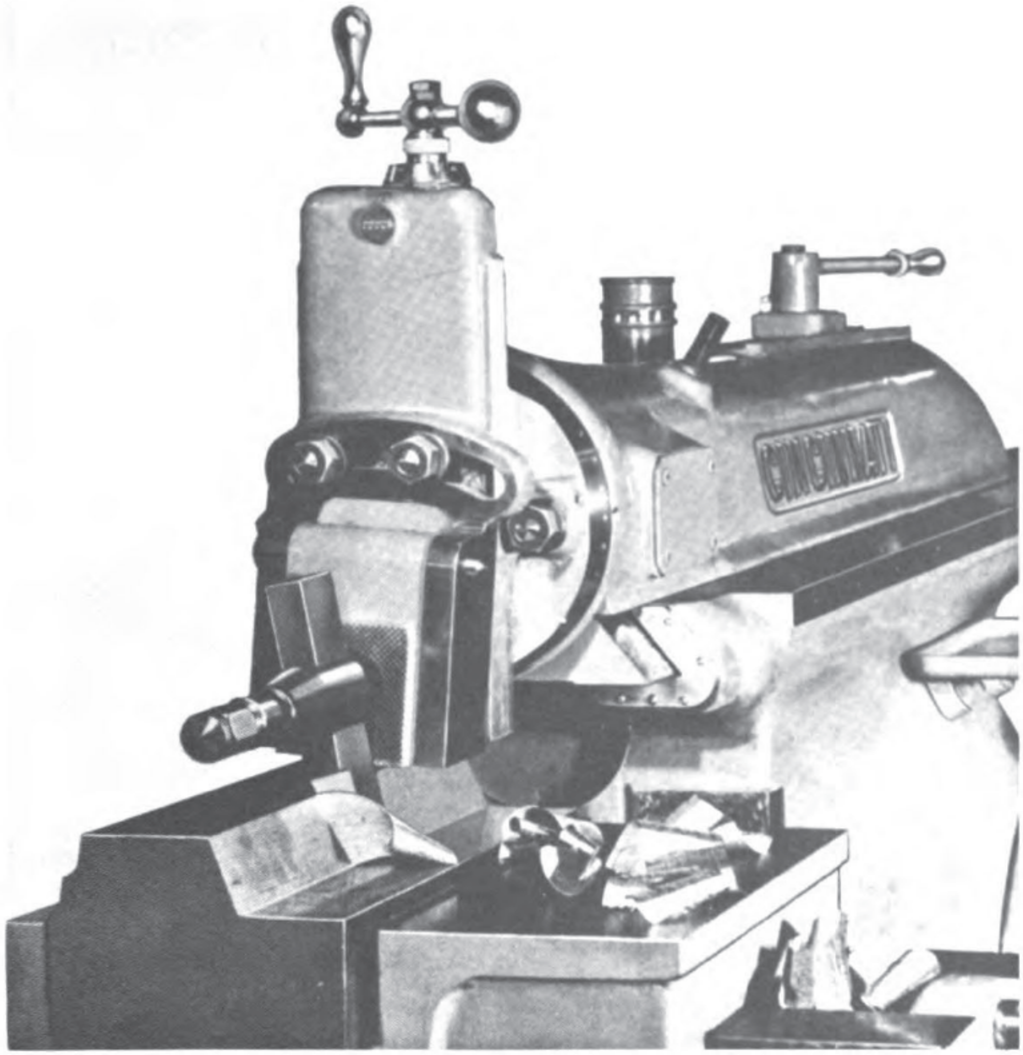
engine lathe, which is used for turning out individual pieces but not intended for mass production work, is shown in figure 5–3. It can be used for outside turning, facing, boring, taper-turning, drilling, threading inside or outside, knurling, and spring winding. With proper attachments, it can also be used for grinding and milling in a limited degree. (See figs. 5–4 and 5–5.) If a great number of pieces are to be made, a turret lathe or an automatic lathe is better for the purpose.



Courtesy Cincinnati Shaper Co.

Figure 5–6.—Standard shaper.

Planing, or surfacing, is done on planers, shapers, and milling machines. On a shaper, the piece is held on a table in a vise or by clamps while a ram moves the tool across it with a reciprocating motion. The table is moved between each stroke by a ratchet-and-lead-screw mechanism. The result is a true, flat finished surface on the piece. (See figs. 5–6 and 5–7.) The shaper can also be used to cut V-blocks, keyways,



Courtesy Cincinnati Shaper Co.

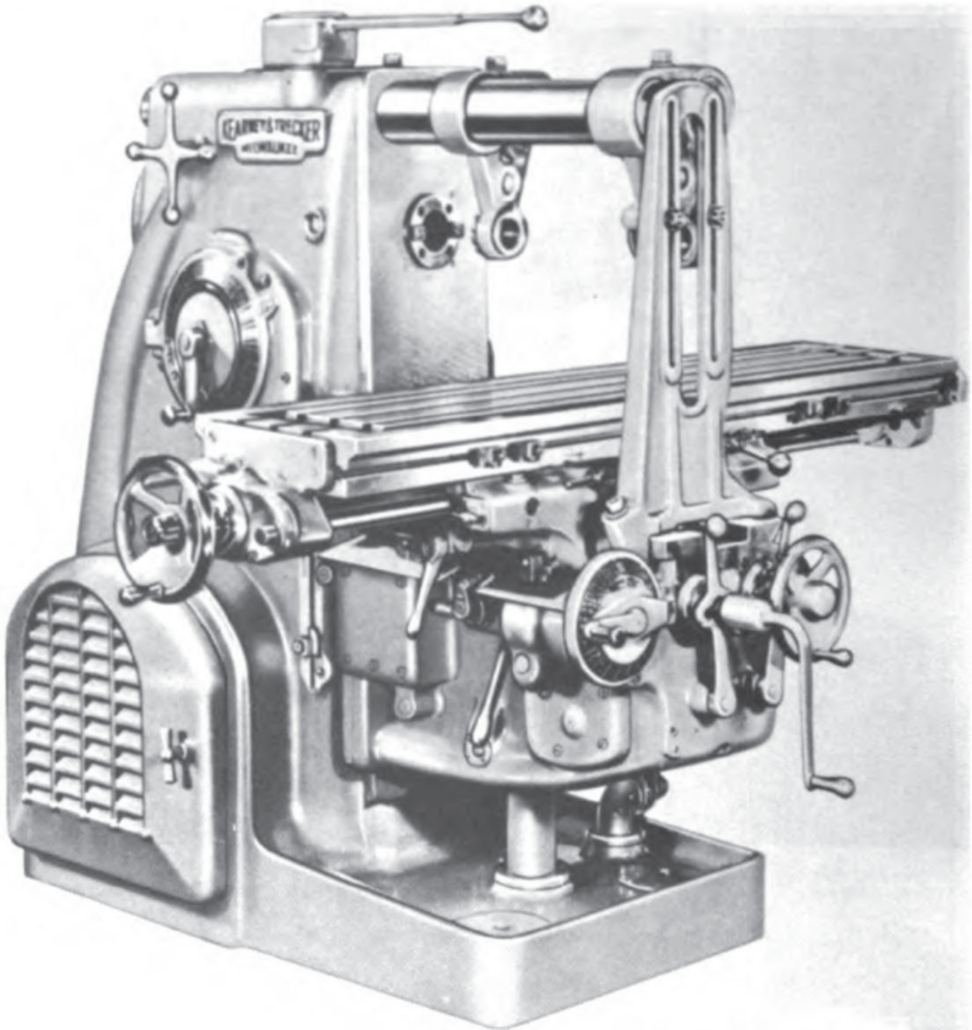
Figure 5–7.—Shaper ram head at work.

dovetails, and a number of other intricate shapes. Special shapers are now widely used for the cutting of gear teeth.

The action of a planer is similar to that of a shaper, except that on a planer, the cutting tool remains stationary while the work is moved past it with a reciprocating motion. Planers are used for most heavy work.

A milling machine has revolving cutters with teeth that remove metal in a small chip at a time. (See fig. 5–8.) Its action is similar to that of a saw. In fact, very thin milling

cutters are called metal cutting saws. The work is fed slowly and uniformly against the cutter by the action of a lead screw in the table on which the work is mounted. (See fig. 5–9.) Milling cutters come in a wide varietv of shapes.

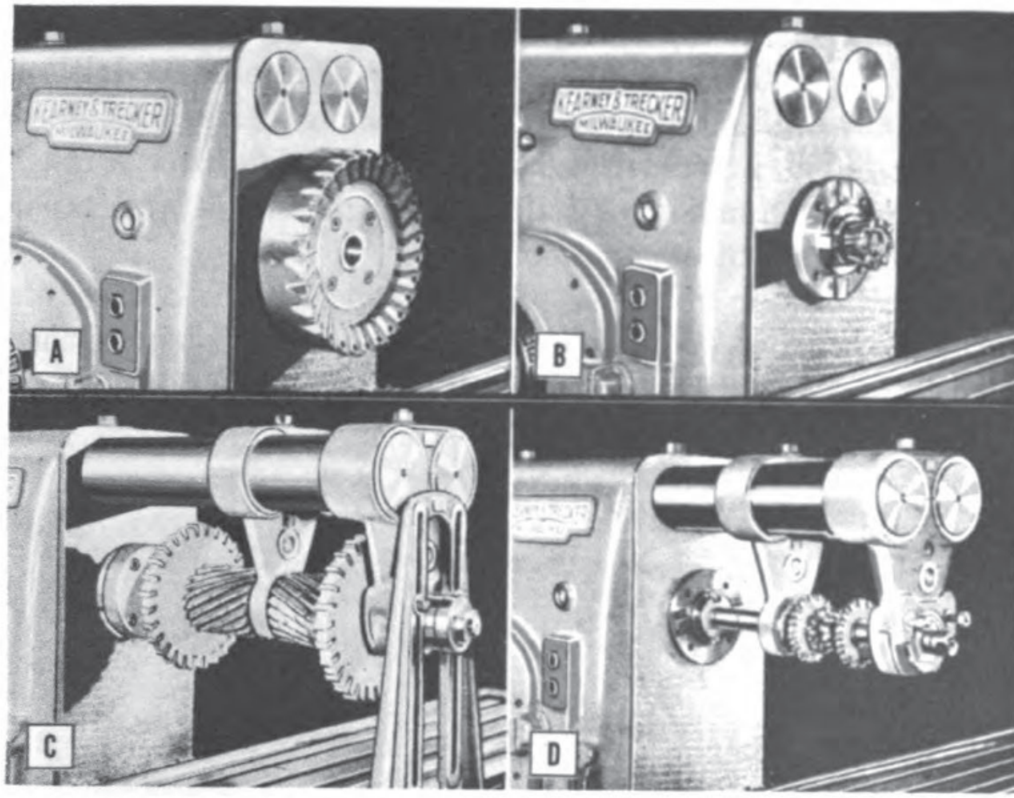


Courtesy Kearney and Trecker Corporation

Figure 5–8.—A milling machine.

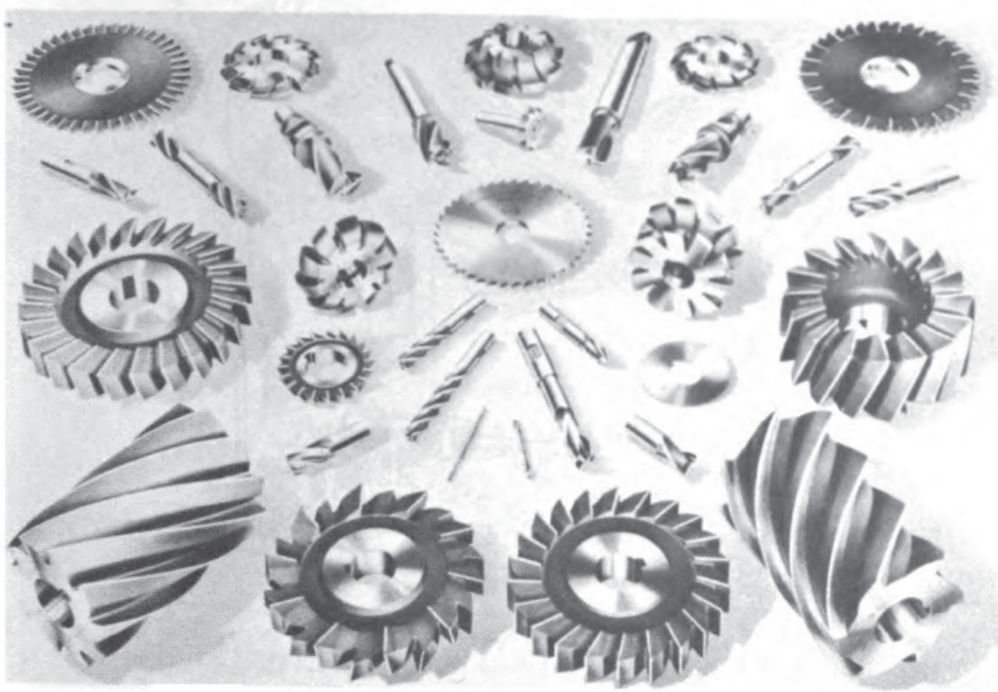
(See fig. 5–10.) Gears can be produced on a milling machine by the use of gear tooth cutters. (See fig. 5–11.) The process is slow, however, and special gear-cutting machines have been designed for mass production work.

HOLES up to 3 inches in diameter are cut with a drill in a



Courtesy Kearney and Trecker Corporation

Figure 5–9.—Four set-ups: A. Heavy duty face milling. B. Light and medium face milling. C. Heavy duty side and slab milling. D. Light and medium side and slab milling.



Courtesy Brown and Sharpe Mfg. Co.

Figure 5–10.—Milling machine cutters.

drill press. (See fig. 5–12.) If the work cannot be moved, small-sized drill bits can be used in a portable hand drill or an electric drill. For a hole of very accurate size and good interior finish, a reamer is used. (See fig. 5–13.) Figure 5–14 shows a number of drills. Straight shank and taper shank drills are most common.

Large holes or holes for which no drill bit is obtainable can be bored with special cutting tools and tool holders either on a lathe or a boring machine. The boring machine is gen-

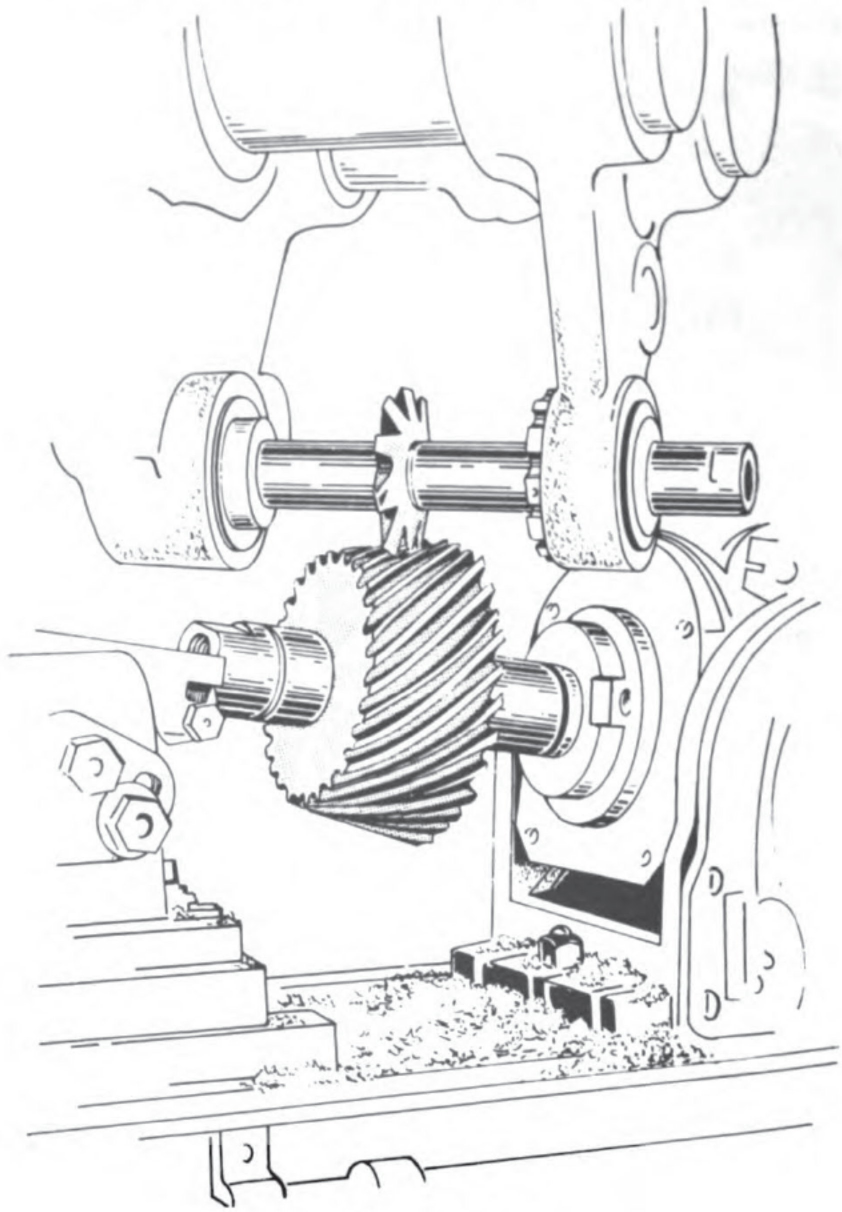
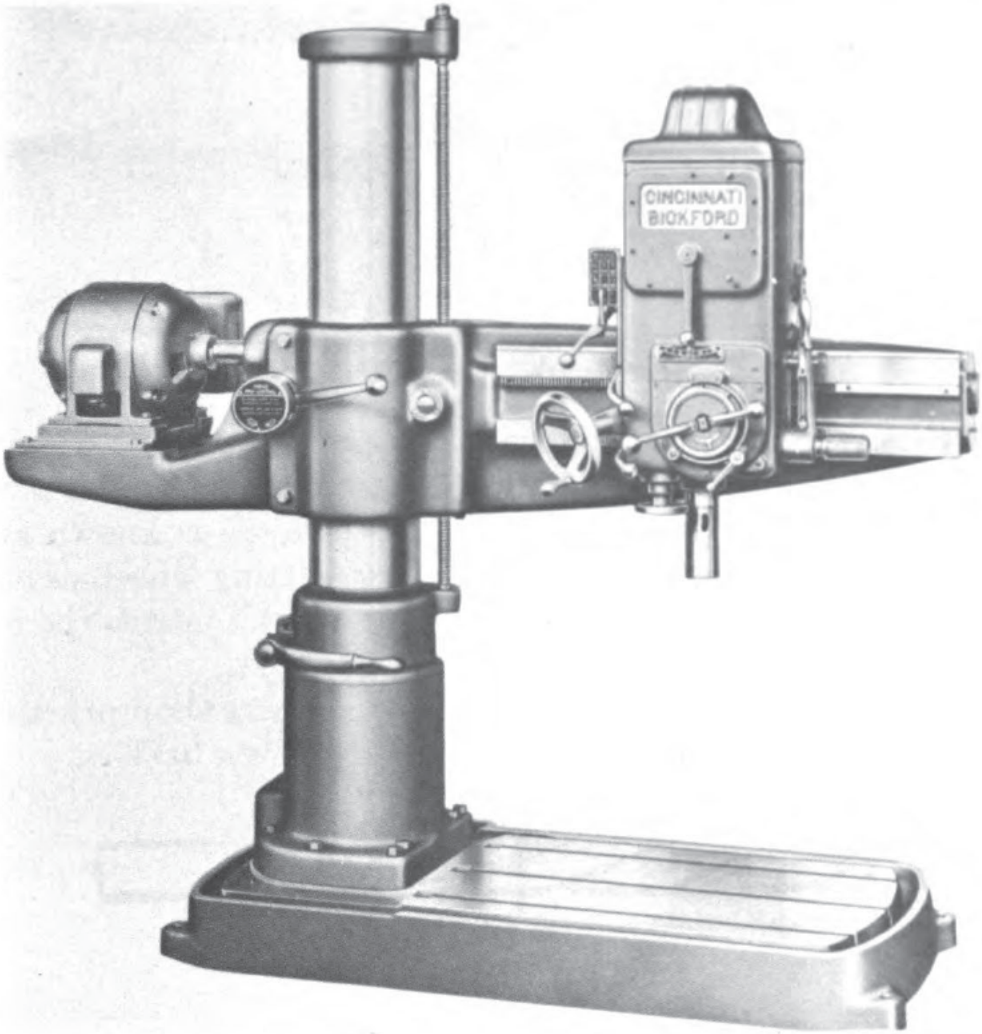


Figure 5–11.—Cutting a gear.

erally used for large and heavy work such as interiors of pump or steam cylinders or large bearings.

Most grinding machines may be classified as surface grinders or cylindrical grinders. Surface grinders are used

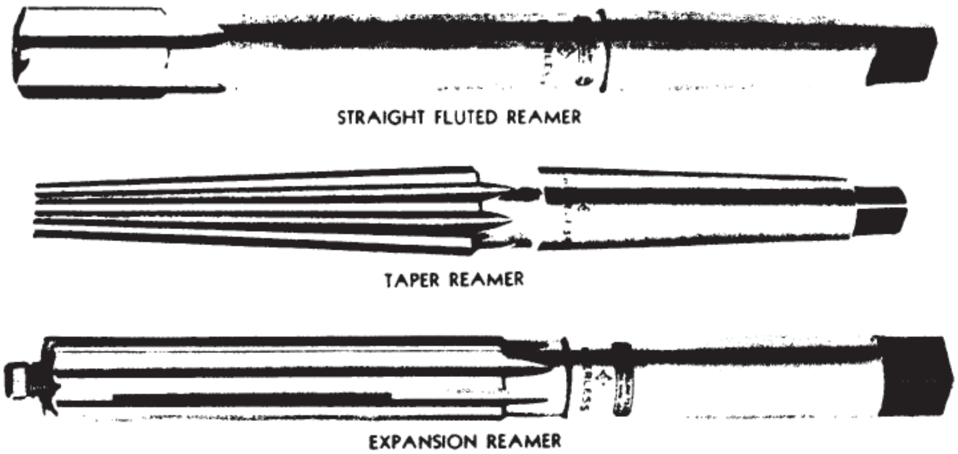


Courtesy of the Cincinnati Bickford Tool Co.

Figure 5–12.—A radial drill press.

to produce a fine finish on a flat surface. A surface grinder with a permanent magnet type of chuck is shown in figure 5–15.

Cylindrical grinders are used to produce a finish on surfaces of revolution, such as cylinders or cones. On some



Courtesy of the Cleveland Twist Drill Co.

Figure 5–13.—Types of reamers.

cylindrical grinders, the work is rotated between centers as on a lathe, while the grinding wheel, revolving at a much higher speed, passes over it. Another type is known as a centerless grinder. In this type, a regulating wheel, usually of the same material as the grinding wheel, controls the rate of feed and the speed of rotation of the work.

For a more detailed description of machine shop practices, read *Machinery Repairman 3 and 2*, NavPers 10530.

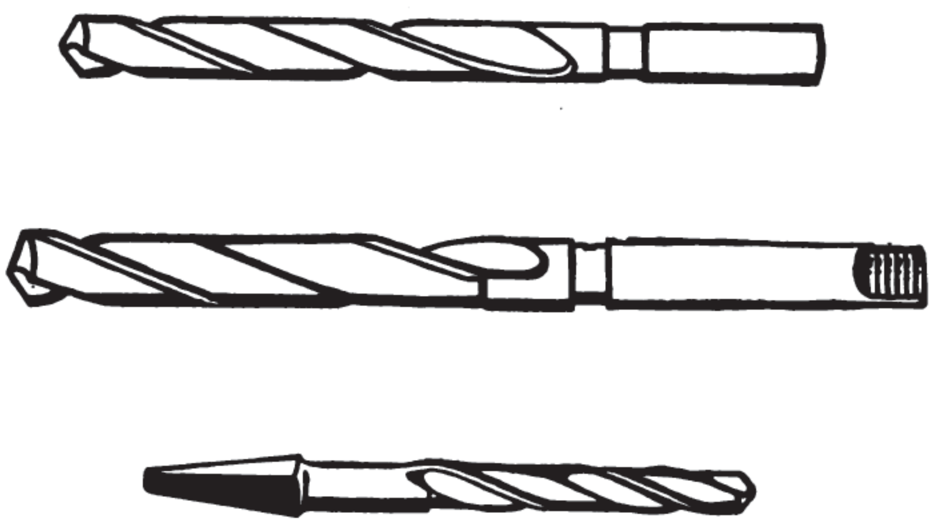
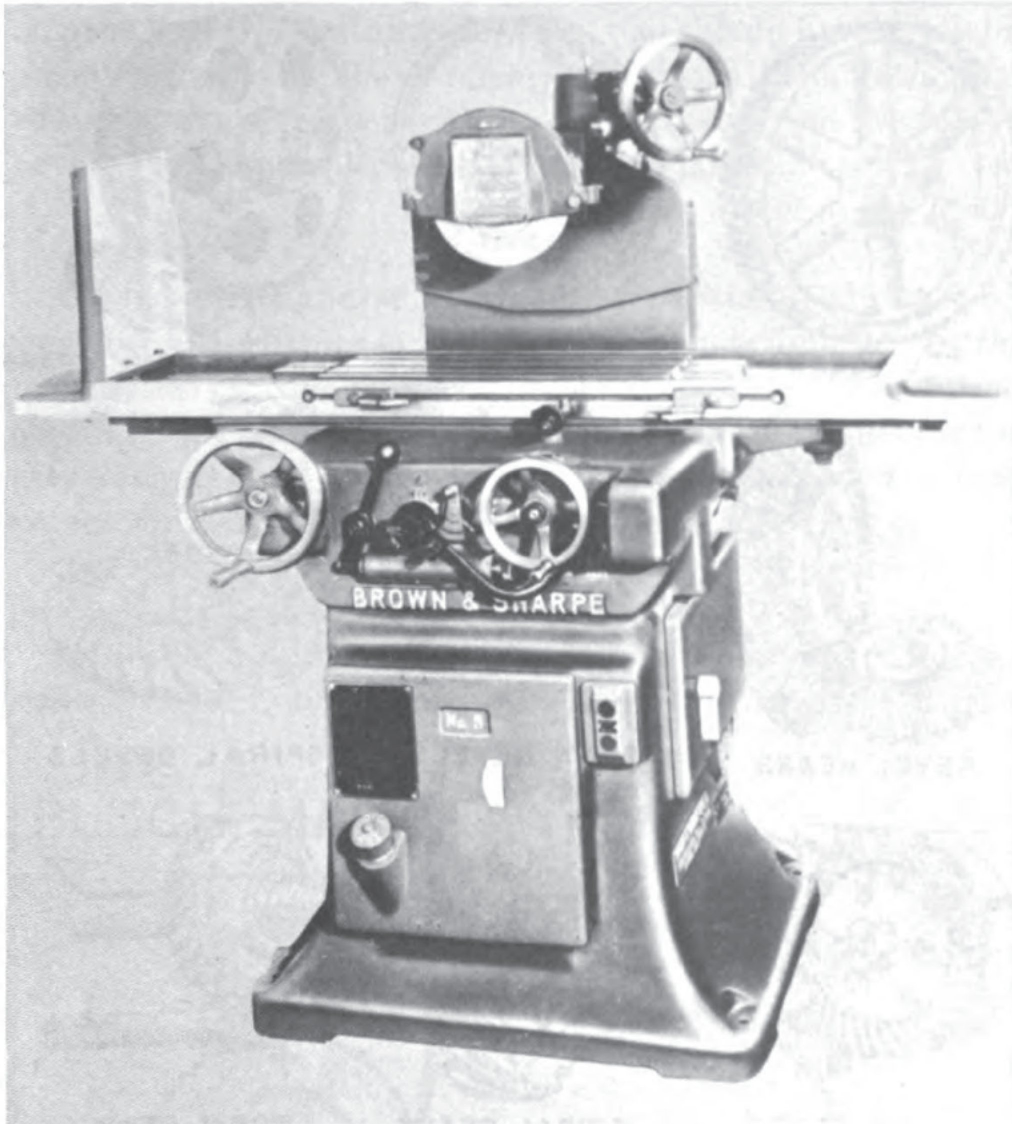


Figure 5–14.—Types of twist drills.

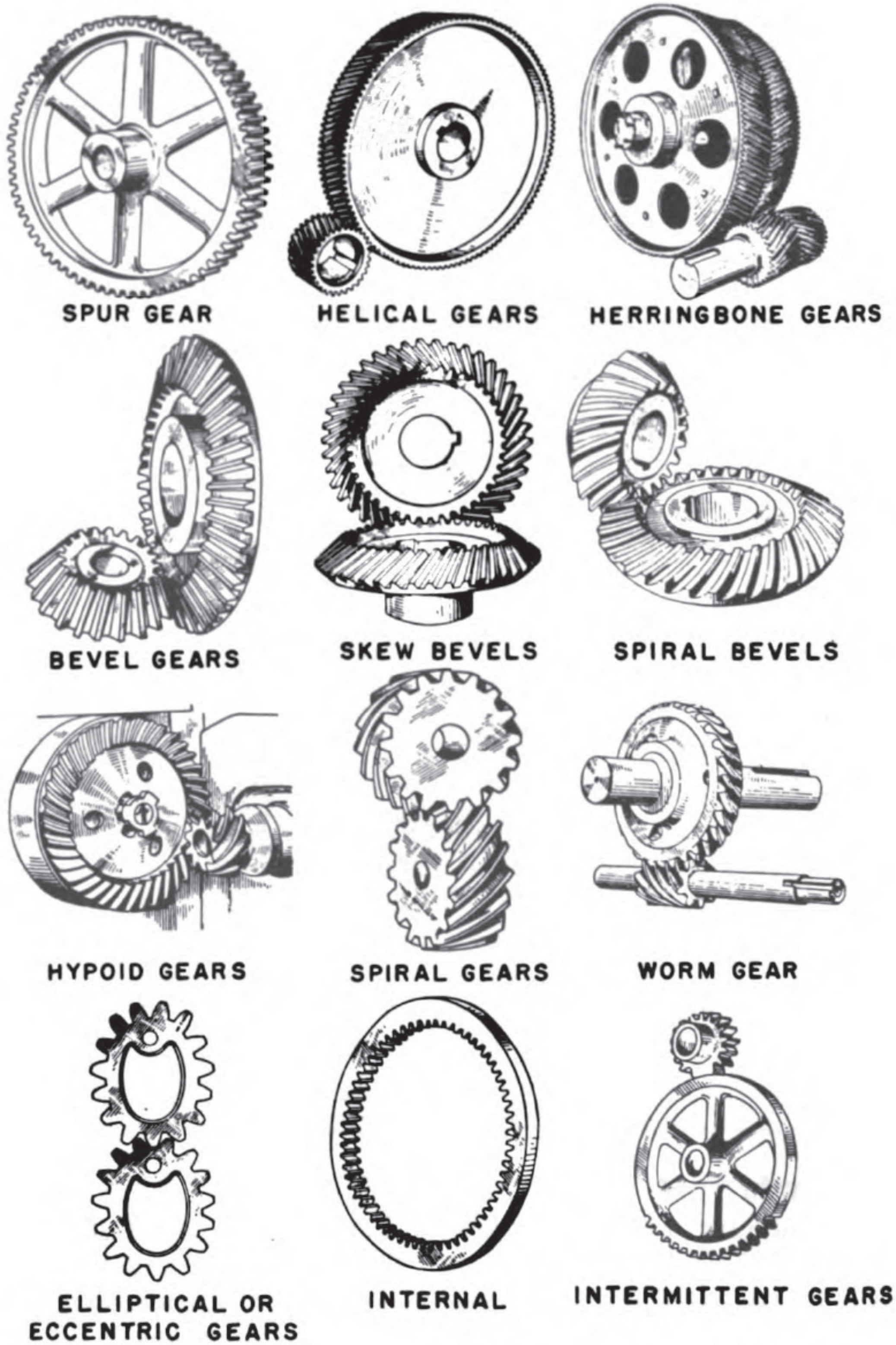


Courtesy Brown & Sharpe Manufacturing Co.

Figure 5–15.—Surface grinder.

DRAWING OF MACHINE PARTS

Certain machine operations require special symbols or dimensioning on the drawing. The finish symbol is discussed briefly in *Draftsman 3*. The machining and dimensioning of drilled, reamed, and tapped holes, and the dimensioning of fasteners are also discussed. A short introduction is given to welding methods and symbols. The Military Standards covering these subjects are listed in chapter 1



By permission from Gear Cutting Practice, *by Colvin and Stanley. Copyright 1937. McGraw-Hill Book Company, Inc.*

Figure 5–16.—Twelve common types of gears.

on page 6 of this training course. You should have available a copy of each of these. You may obtain them from your educational services officer who orders them from the nearest naval district publication and printing office.

Gears

Aboard ships and at naval shore facilities, gears have always been highly essential elements of machinery. In the modern Navy, the emphasis on speed, power, and compactness in naval machinery has created special problems for the gear designer. The 12 types of gears most commonly used are shown in figure 5–16. The four types which are ordinarily cut in machine shops are spur gears, bevel gears, helical gears, and worm gears.

To better understand gears, first consider the action of smooth-faced cylinders or wheels in rolling contact. Figure

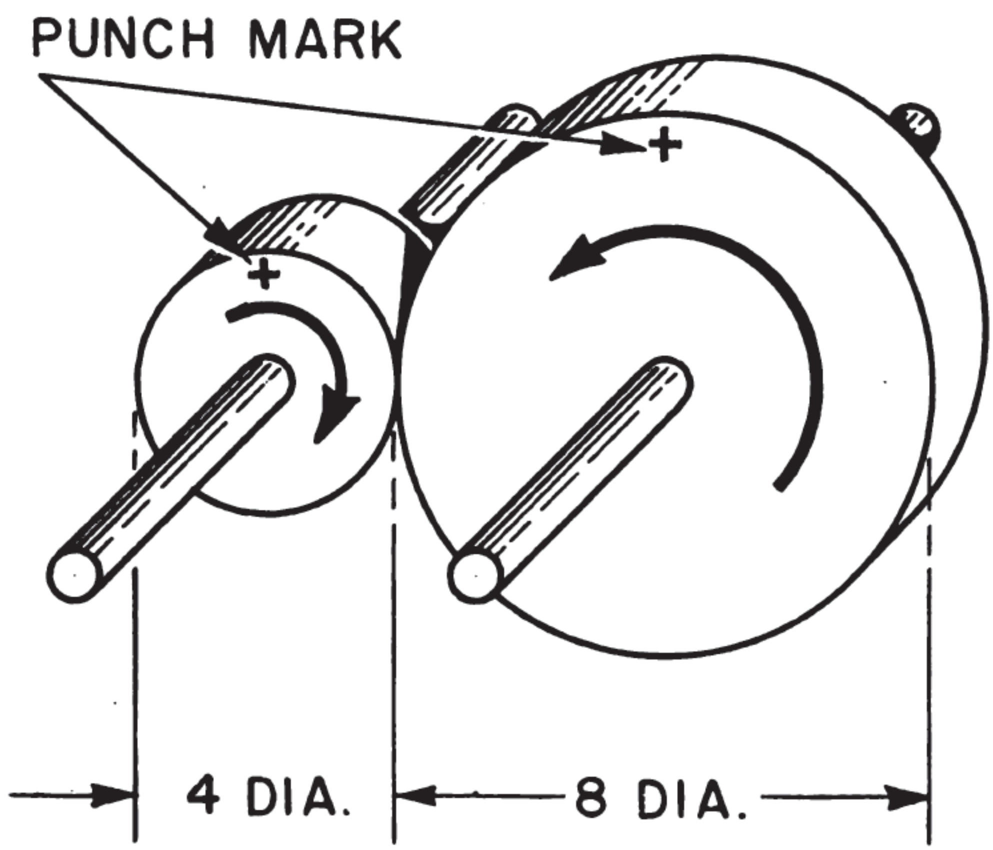


Figure 5–17.—Movement of two cylinders in rolling contact.

5–17 shows two cylinders, one with a diameter of 4 inches and the other with an 8-inch diameter. If a point is marked near the edge of each of the cylinders and the cylinders are rotated, one mark will have moved an inch when the other has moved an inch. If the smaller wheel makes ½ of a revolution, the mark on it moves 6¼ inches along the circumference. At the same time, the larger wheel moves 6¼ inches as well, but it makes only ¼ of a revolution. If the smaller wheel makes a complete revolution, the larger wheel will make ½ of a revolution. The smaller wheel must make two complete revolutions to one revolution for the larger. Thus the speed ratio (2: 1) is the inverse ratio of the circumference ($4\pi : 8\pi$), and it is also the inverse ratio of the diameters (4:8).

If there were 10 gear teeth on the wheels to each inch of diameter, the speed ratio would become the inverse ratio of the number of teeth (40:80). In order to form the teeth on these cylinders, the upper part of each tooth would have to be built up from the smooth face of the cylinder and material removed between the teeth to a slightly greater depth below the face of the cylinder. The 4-inch and 8-inch diameters would then exist only in theory. Nevertheless, these imaginary circles play an important part in the design of the gears and are called the PITCH CIRCLES. Of course, in practice, gear teeth are never built up. The gear is turned out as a blank to the correct outside diameter, and metal is removed to the whole depth of the teeth.

Other terms used in describing gear teeth are illustrated in figure 5–18.

PITCH DIAMETER (PD).—Diameter of the pitch circle (or line) which equals the number of teeth divided by the diametral pitch.

NUMBER OF TEETH (N).—The diametral pitch multiplied by the diameter of the pitch circle (DP x PD).

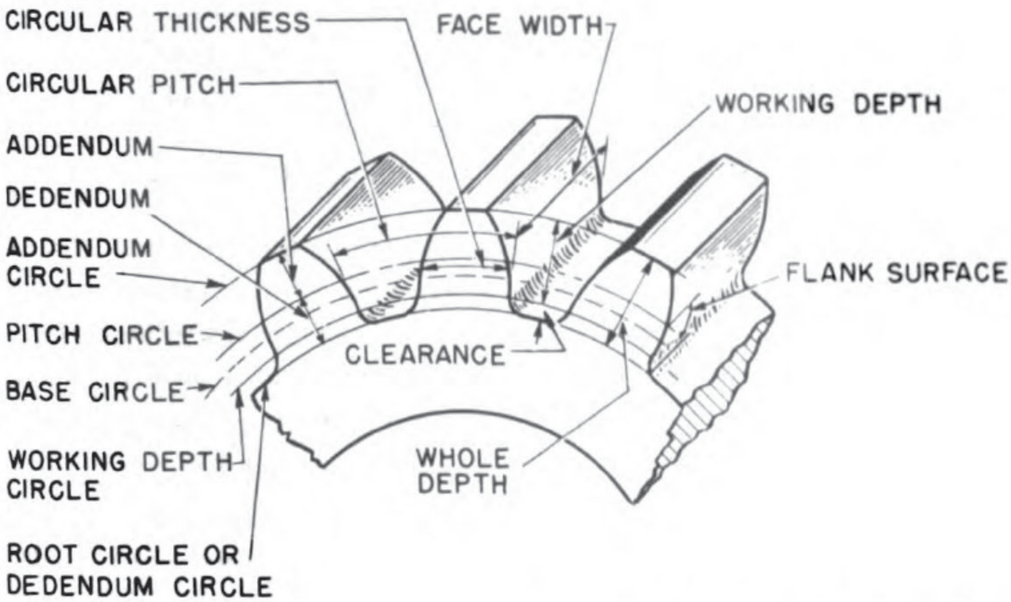
DIAMETRICAL PITCH (DP).—The number of teeth to each inch of the pitch diameter or the number of teeth divided

by the pitch diameter. Diametral pitch is usually referred to simply as PITCH.

ADDENDUM CIRCLE (AC).—The circle over the tops of the teeth.

OUTSIDE DIAMETER (OD).—Diameter of the addendum circle.

CIRCULAR PITCH (CP).—Length of the arc of the pitch circle between the centers or corresponding points of adjacent teeth.



Courtesy International Textbook Co.

Figure 5–18.—Gear tooth nomenclature.

ADDENDUM (A).—The height of the tooth above the pitch circle or the radial distance between the pitch circle and the top of the tooth.

DEDENDUM (D).—The length of the portion of the tooth from the pitch circle to the base of the tooth.

CHORDAL PITCH.—The distance from center to center of teeth measured along a straight line or chord of the pitch circle.

ROOT DIAMETER (RD).—The diameter of the circle at the root of the teeth.

Clearance (C).—The radial distance between the bottom of a tooth and the top of a mating tooth.

Whole depth (WD).—The distance from the top of the tooth to the bottom, including the clearance.

Face.—The working surface of the tooth above the pitch line.

Flank.—The working surface of the tooth below the pitch line.

Thickness.—The width of the tooth, taken as the chord of an arc of the pitch circle.

Circular pitch is the distance in inches measured from the intersection of the face and flank of one tooth to the same point on the adjacent tooth. That is, it is equal to $\frac{\pi PD}{N}$ or $\frac{\pi}{DP}$. On a rack, it is called linear pitch.

Before the days of form cutters, indexing devices, and gear-cutting machines, most gears were cast from patterns and then filed more or less into shape. Circular pitch was then used to designate the size of the gear teeth, and easily measured pitches, such as ¼ inch, ½ inch, ¾ inch, were used. When making a pattern, the patternmaker used the circular pitch or the chordal pitch to space the teeth in the gear.

Today, circular pitch is used only in calculations for gears of coarse pitch, because for smaller pitches, a simpler and better system has been devised. This is the diametral pitch system, which is based on the diameter of the pitch circle, rather than on the circumference. With this system, indexing devices may be set to accurately space the teeth and therefore there is seldom any need to calculate circular pitch or chordal pitch. Mating gears must always have the same diametral pitch.

Spur gears may be distinguished by the fact that the teeth are cut squarely across the outer rim of the gear blank in a direction parallel to the gear shaft axis. (See fig. 5–18.) On a standard involute spur gear, the tooth of one gear bears against the tooth of the mating gear at an angle of 14½ degrees. This is called the pressure angle. Another

spur gear tooth is the 20° stub tooth. It is much like the standard $14\frac{1}{2}°$ tooth, except that it has a pressure angle of 20° and is a shorter tooth. (See fig. 5–19.)

The working depth of a spur gear tooth is equal to 2 divided by the pitch. That is, 12-pitch teeth are $\frac{2}{12}$-inch

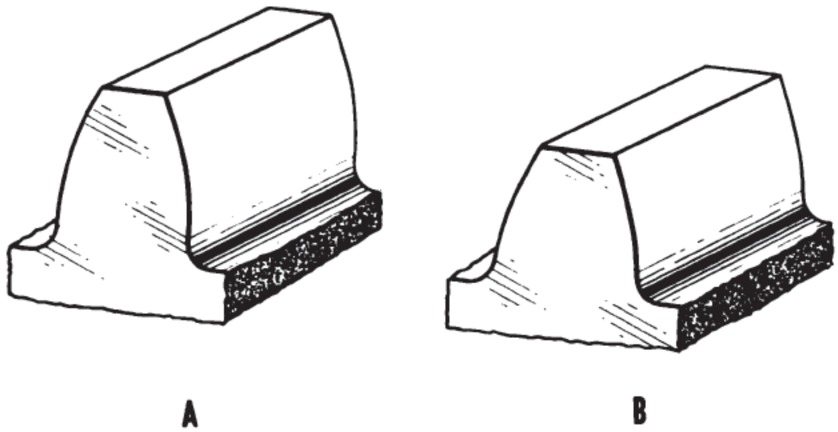


Figure 5–19.—A. A standard $14\frac{1}{2}°$ spur gear tooth. B. A 20° spur gear stub tooth.

deep and 8-pitch teeth are $\frac{2}{8}$-inch deep. Remember that pitch means the number of teeth to each inch of the pitch diameter, or the number of teeth divided by the pitch diameter. Conversely, the pitch diameter is equal to the number of teeth divided by the pitch.

It is seldom necessary to draw an entire gear in detail, or even to draw any teeth at all. A conventional working drawing of a spur gear is shown in figure 5–20. To draw a gear that has 24 teeth and 8 pitch, divide the 24 by 8 to get 3 inches, the pitch diameter. Draw the pitch circle with this diameter. (See fig. 5–20.) Note that the pitch circle is usually indicated by a broken line with long and short dashes alternating. Since the working depth will be equal to 2 divided by the pitch 8, or $\frac{2}{8}$, the outside circle should be drawn with $\frac{1}{8}$ of an inch greater radius than the pitch circle, and its diameter will be $3\frac{2}{8}$ inches. The root circle should be drawn with $\frac{1}{8}$ of an inch smaller radius than the pitch circle, or $2\frac{6}{8}$ inches in diameter, except when allowance is also made for clearance.

The clearance can be found by dividing a constant by the pitch. For standard involute teeth, the constant used is 0.157. Clearance is provided in the shape of the formed cutter. It is not always necessary, however, to calculate the clearance for the purpose of drawing a root circle.

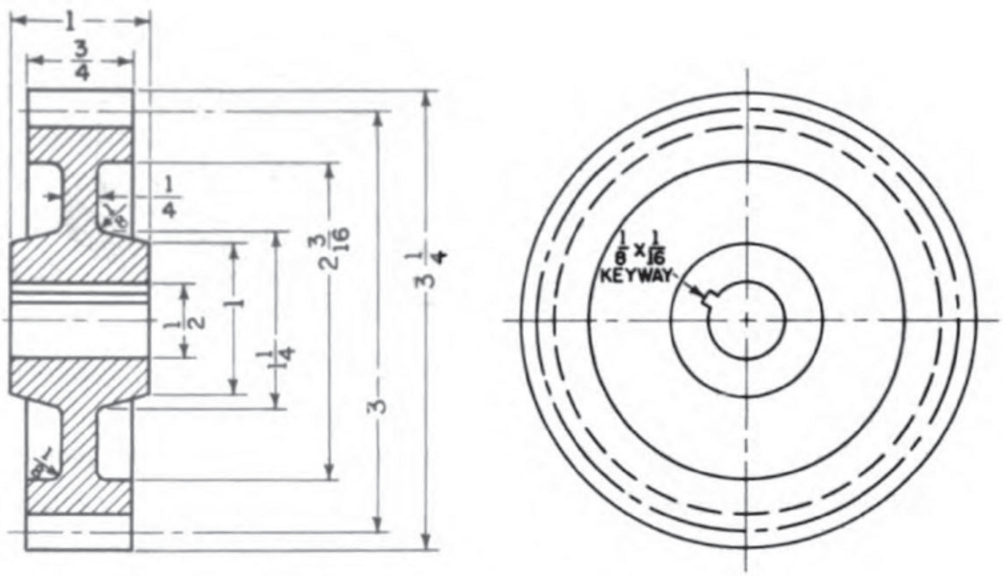


Figure 5–20.—Working drawing of a spur gear.

Although it is seldom necessary for the draftsman to draw gears in detail, he should know how to draw at least one form of gear with the teeth. For this reason, instructions on drawing an involute tooth form on a wheel and rack are included here. The diameter of the pitch circle (PD) on the wheel is given as 12 inches and the number of teeth (N) as 36. It would be well for you to review at this time the general instructions on involute curves in chapter 4.

1. The values in inches are found, to three decimal places when necessary, for each of the following dimensions:

$$\text{DP (pitch)} = \frac{N.}{PD}$$

$$\text{WD (whole depth of teeth)} = \frac{2.}{DP}$$

$$\text{A (addendum)} = \frac{WD.}{2}$$

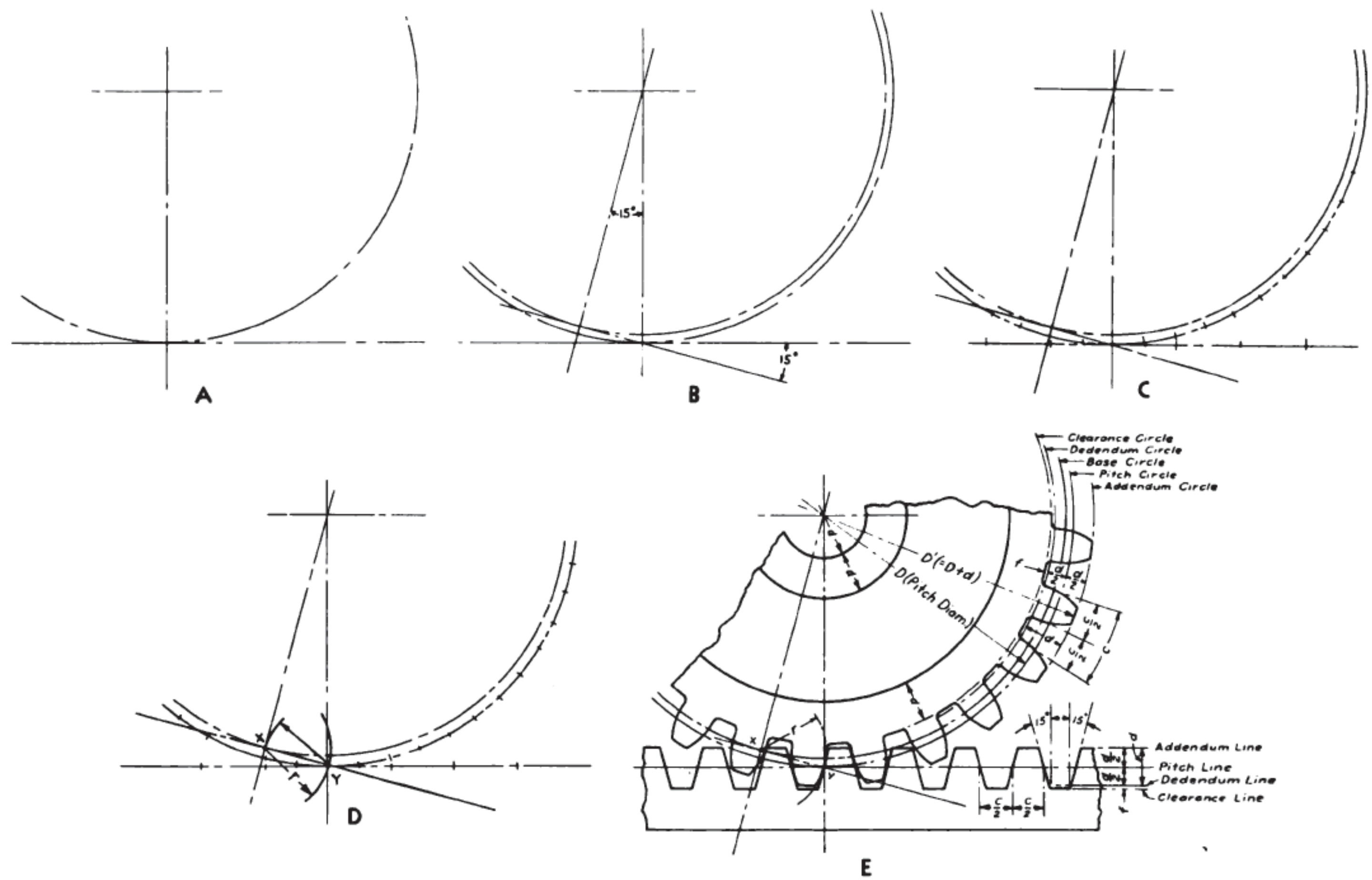
$$\text{OD (outside diameter)} = \text{PD} + 2\text{A}.$$
$$\text{D (dedendum)} = \text{A} = \frac{\text{WD.}}{2}$$
$$\text{RD (root diameter)} = \text{PD} - 2\text{D}.$$
$$\text{CP (circular pitch)} = \frac{3.1416.}{\text{DP}}$$
$$\text{T (thickness of teeth)} = \frac{\text{CP.}}{2}$$

2. Locate the center of the wheel and draw the pitch circle with a radius of ½ the pitch diameter. Draw the center lines of the wheel, and at the point where the vertical center line intersects the bottom of the pitch circle, draw a horizontal line to represent the pitch line of the rack. (See fig. 5–21A.)

3. In order to draw the teeth by the approximate method given here, a circle called the BASE CIRCLE, which falls between the pitch circle and the root circle, must be drawn. In order to locate this circle, draw a line inclined at an angle of 15° through the intersection of the vertical center line and the pitch circle, and a second line from the center of the wheel inclined at an angle of 15° to the vertical center line. (See fig. 5–21B.) The distance from the intersection of these two lines and the center of the wheel is the radius for drawing the base circle. Fifteen degrees was selected because it is a convenient angle to draw and closely approximates the 14½ degree pressure angle of the teeth.

4. Set the small dividers at a distance equal to the thickness of the teeth and lay off the teeth on the pitch circle and then on the pitch line of the rack. The sides of the teeth in the rack are drawn at an angle of 15° with the vertical, as shown in figure 5–21E. The sides of the teeth in the wheel are drawn with a radius *r* as indicated in figure 5–21D.

5. With a center on the base line, draw an arc with a radius of *x* to *y* through one of the points laid off with the dividers and repeat the procedure for all other points. In order to determine where the center should fall on the base circle, first draw an arc cutting the base circle with a center on one of the points on the pitch circle. Both sides of the teeth may be drawn by this method. (See fig. 5–21D.)



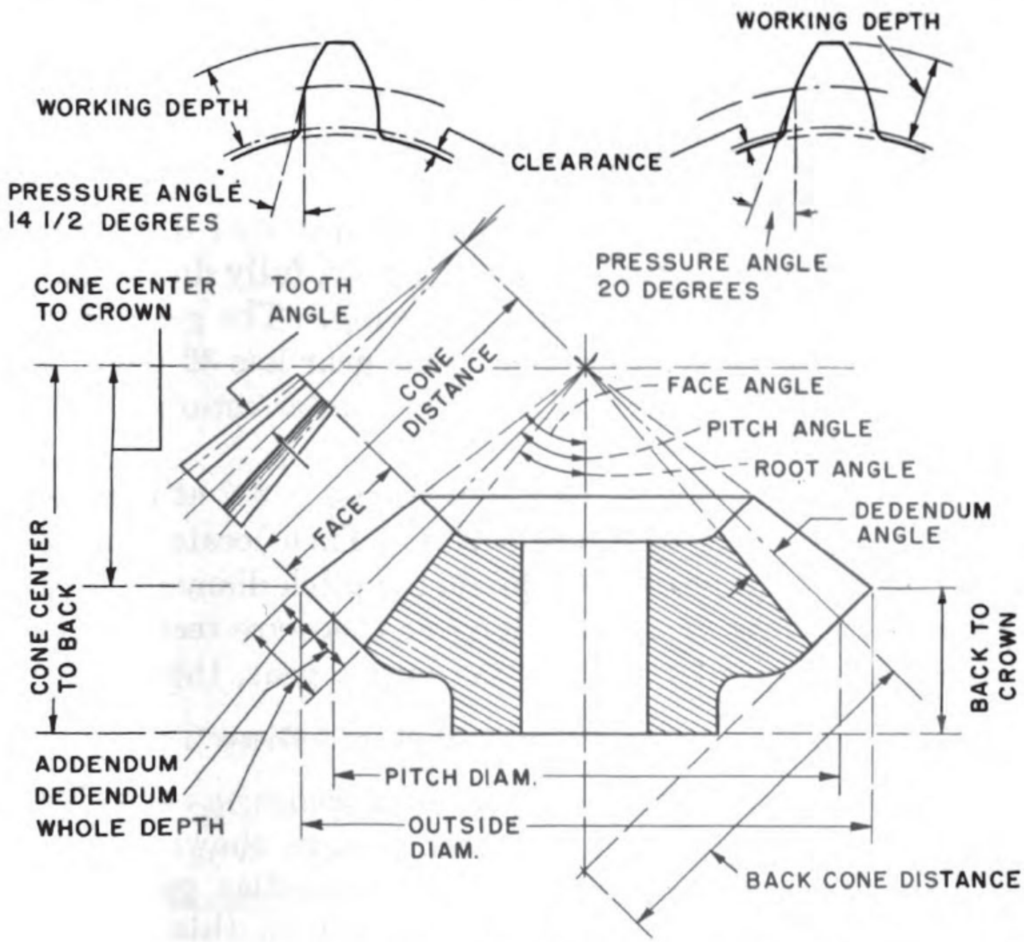
Courtesy *Columbia Technical Institute*

Figure 5–21.—Approximate method of drawing teeth on a wheel and rack.

6. In completing the teeth of the wheel, draw fillets with a radius of 1/16 inch connecting the sides of the teeth with the clearance circle. There are no fillets in the rack shown in this drawing. (See fig. 5–21E.)

RACK TEETH.—A rack may be compared to a spur gear that has been straightened out. The pitch of the rack teeth must equal the circular pitch of the mating gear. The depth of the tooth is calculated in the same manner as the depth of a spur gear tooth.

INTERNAL SPUR GEARS.—Internal gears may be considered as circular metal bands with teeth on their inside surfaces. (See fig. 5–16.) These gears are proportioned like a standard spur gear turned outside in, or with dedendum and ad-



After a drawing from Gear Cutting Practice, *by Colwin and Stanley. Copyright 1937 McGraw-Hill Book Company, Incorporated*

Figure 5–22.—Parts of a bevel gear.

dendum in reverse positions. The rules for finding the dimensions of an internal spur gear, therefore, are similar in most cases to those for external gears.

STUB TOOTH GEARS.—Stub involute tooth gears are largely used in automotive drives because of their strength. This type of gear tooth has a 20° pressure angle and is short and thick. (See fig. 5–19.) Three systems of stub tooth gearing are in general use. These are the Nuttall, the Fellows, and the American Standards Association.

BEVEL GEARS have teeth cut on an angular face for transmitting motion between shafts that are set at an angle to each other but are in the same plane. (See fig. 5–16.) When the gears have the same number of teeth and their shafts are at right angles, they are usually referred to as miter gears.

In addition to the gear nomenclature already given, you should know a few more terms which apply only to bevel gears. The names of the parts of a bevel gear are given in figure 5–22.

Laying out a bevel gear is more complicated than laying out a spur gear. A full section of a gear, fully dimensioned, will usually serve as a working drawing. The gears shown in figure 5–23 have an 8 pitch. One gear has 32 teeth, and the mating gear has 16. The shaft intersection is at 90 degrees.

First draw the center lines intersecting at 90° at the center point O, as shown in figure 5–23A. Then locate the pitch lines. Since the gears are 8 pitch, the pitch diameter will be as many eighths of an inch long as there are teeth in each gear. There are 32 teeth in the larger gear, therefore the pitch diameter will be $\frac{32}{8}$ or 4 inches. Draw lines parallel to the center line for the gear and 2 inches on each side of it to define the limits of the pitch line, as shown in figure 5–23A. Locate the pitch line of the smaller gear in the same manner. Since there are 16 teeth in this gear, the pitch line, or pitch diameter will be $\frac{16}{8}$ or 2 inches, extending 1 inch on each side of the center line.

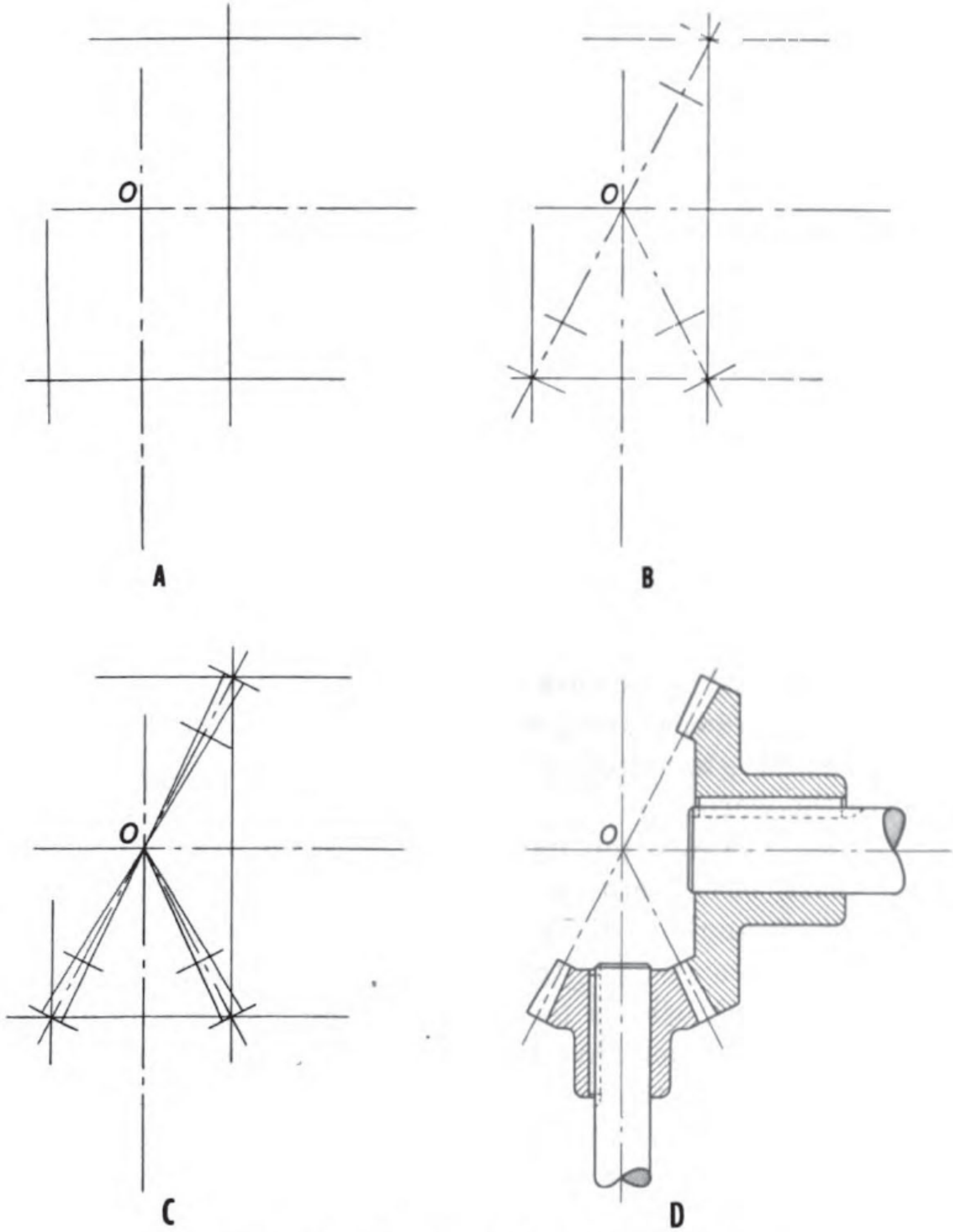


Figure 5–23.—Working drawing of a bevel gear.

Then draw lines through the end points of the pitch lines to the center O. These lines are the pitch cones and O is the cone vertex. (See fig. 5–23B.) Perpendicular to the pitch cone elements, draw the lines that form the material conical surfaces of the gear teeth. On these lines, lay off the addendum and dedendum of the gear teeth. Since the teeth

are 8 pitch, each of these will be $\frac{1}{8}$ of an inch from the pitch line. (See fig. 5–23C.) Note that the addendum of one gear is the dedendum of the other and vice versa. No allowance for clearance has been made on this drawing. If clearance is to be allowed for, two other lines must be drawn slightly further from the pitch line.

Draw lines from these points to the cone center O, forming the faces and bottom of the teeth. Then draw the lines defining the width of the gear face. (See fig. 5–23B.) Note that the width of the gear face is made $\frac{1}{3}$ the pitch cone radius for gears up to 3 inches in pitch diameter, and $\frac{1}{4}$ the pitch cone radius for gears with 3 to 20 inches of pitch diameter.

Finally, complete the drawing of the gears, including section lining and dimensioning. (See fig. 5–23D.)

WORM GEARING is used when a large reduction in velocity is desired or when considerable increase in mechanical advantage is required. As shown in figure 5–16, a worm gear set combines a screw or worm with a worm wheel which has helical teeth and is mounted on a shaft, usually at right angles to that of the worm.

HELICAL GEARS, often incorrectly referred to as spiral or skew gears, have teeth cut across the outer rim of the gear blank at an angle to their axis, so that they are similar to the thread of a screw. (See fig. 5–16.) Helical gears are commonly made with a tooth angle of 45°, since this angle provides a very efficient and durable gear, although any angle which permits the teeth to engage properly may be used.

Helical gears may be used to transmit power between shafts that are parallel or between shafts that are not parallel and not in the same plane. Their action is smoother and quieter than spur gears, but they develop more tooth friction and produce a certain amount of end thrust on the shaft.

Helical Springs

Helical springs may be wound of either wire or flat material. A familiar form of flat spring is the spring lockwasher. Wire springs may be drawn in true orthographic

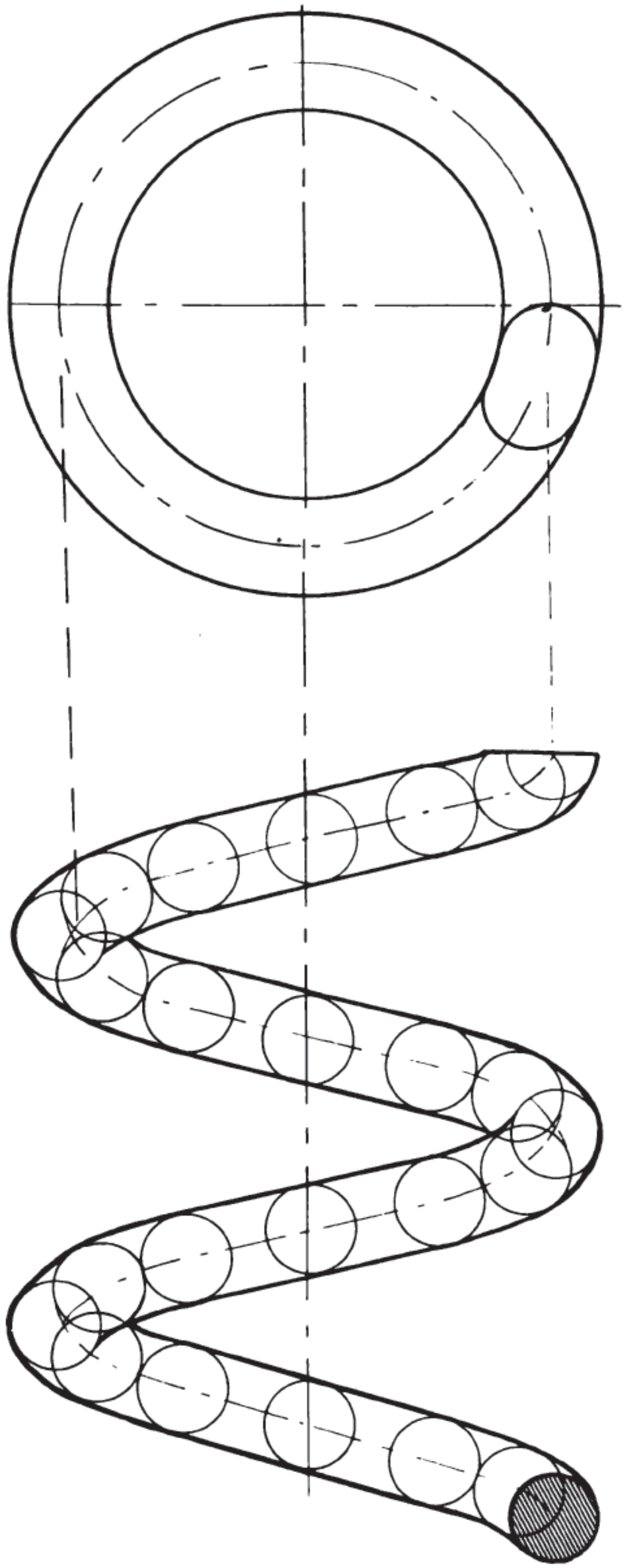


Figure 5–24.—Method of drawing a helical spring in orthographic projection.

projection, or they may be drawn as conventional representations.

The method of drawing a true helical spring in detail is shown in figure 5–24. The center line of the coil is a true

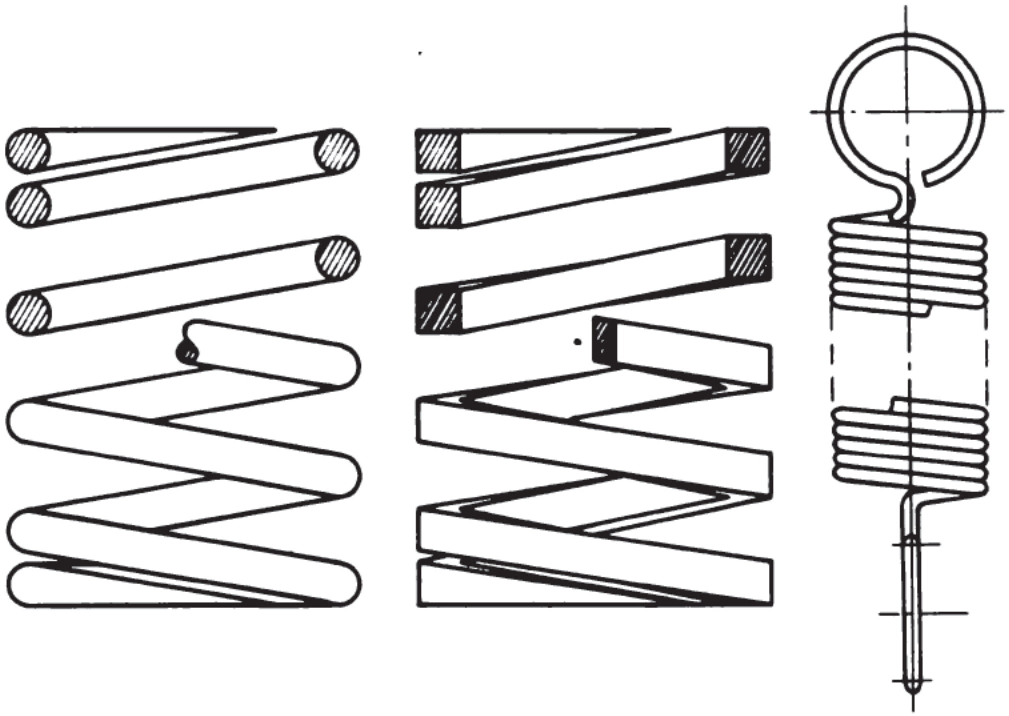


Figure 5–25.—Representations of common types of helical springs.

helix drawn as described in chapter 4. Along this helical line, a number of circles of the diameter of the wire are drawn. These are then enclosed in curves which form the outline of the spring.

This true method is seldom used, however, and springs, like screw threads, are usually drawn with straight lines. In this case, the only difficulties may consist of getting the correct number of coils in the required space and finishing the squared or ground ends. Sometimes the neatest and most

Figure 5–26.—Single line representations of springs.

satisfactory way of drawing a spring is in cross section. Figure 5–25 shows views of common types of helical springs. Note that the ends may be squared, ground, or both squared and ground.

Springs may be drawn as single lines on working or assembly drawings. (See fig. 5–26.)

QUIZ

1. What is the difference between ferrous and nonferrous metals?
2. What is the product of the blast furnace called?
3. Name three important ferrous metals made by refining pig iron.
4. What qualities of cast iron cause it to be limited in use?
5. What two things are present in all steels?
6. How does low carbon steel differ from steel with a higher carbon content?
7. What is one of the most utilized qualities of copper?
8. Name (a) one important alloy containing zinc; (b) one important use of pure zinc.
9. Why is pure aluminum usually combined with alloying elements such as magnesium, copper, nickel, and silicon?
10. What are the most common forms of heat treating for ferrous metals?
11. What are the principal differences between thermoplastic and thermosetting plastics?
12. Why are some metal products which have been produced by casting or rolling later machined?
13. What is casting?
14. What does the draft of a casting refer to?
15. What is forging?
16. What does the process of extruding involve?
17. Name the common cutting processes of machine finishing.
18. Why is a grinding process used on a metal part?
19. Where will most of the material and articles supplied by the Navy be listed?
20. What is the diametral pitch (DP) of a gear?
21. (a) What is the addendum (A) of a gear? (b) Dedendum (D)?
22. What distinguishes a spur gear from other types of gears?
23. Are the teeth usually drawn on working drawings of spur gears?
24. What are bevel gears?

CHAPTER 6

DEVELOPMENT OF SURFACES

INTRODUCTION

A surface has two dimensions—length and width. It is bounded by lines which are either straight or curved. The surface itself may be PLANE, PLANE-CURVED as the peripheral surface of a cylinder, WARPED as the surface of a screw thread, or DOUBLE CURVED as the surface of a sphere. A plane surface is flat. A plane curved surface can be unrolled and laid out flat. This is called DEVELOPING the surface. A warped surface or a double-curved surface cannot be developed except approximately.

In figure 6–1, a number of three-dimensional figures are illustrated. Try to form a mental picture of what would happen if the surfaces of these figures were unfolded or unrolled and laid out in a flat plane. The polyhedrons, of course, would be merely a system of connected squares, triangles, or other polygons. A cylinder with parallel ends would unroll into a parallelogram. A cone would unroll into a section of a circle. However, warped surfaces could not be made to lie flat, and double-curved surfaces present a similar problem.

Warped and double-curved surfaces can be produced in sheet metal only through the application of pressure in such a way as to cause a flow of metal sufficient for the shape to be retained after the pressure is released. For example, automobile fenders and body sections are made in this way. Concentric articles, like metal bowls, can be spun from flat sheet metal on a lathe. Pressure is applied with tools made for the purpose while the metal is spinning.

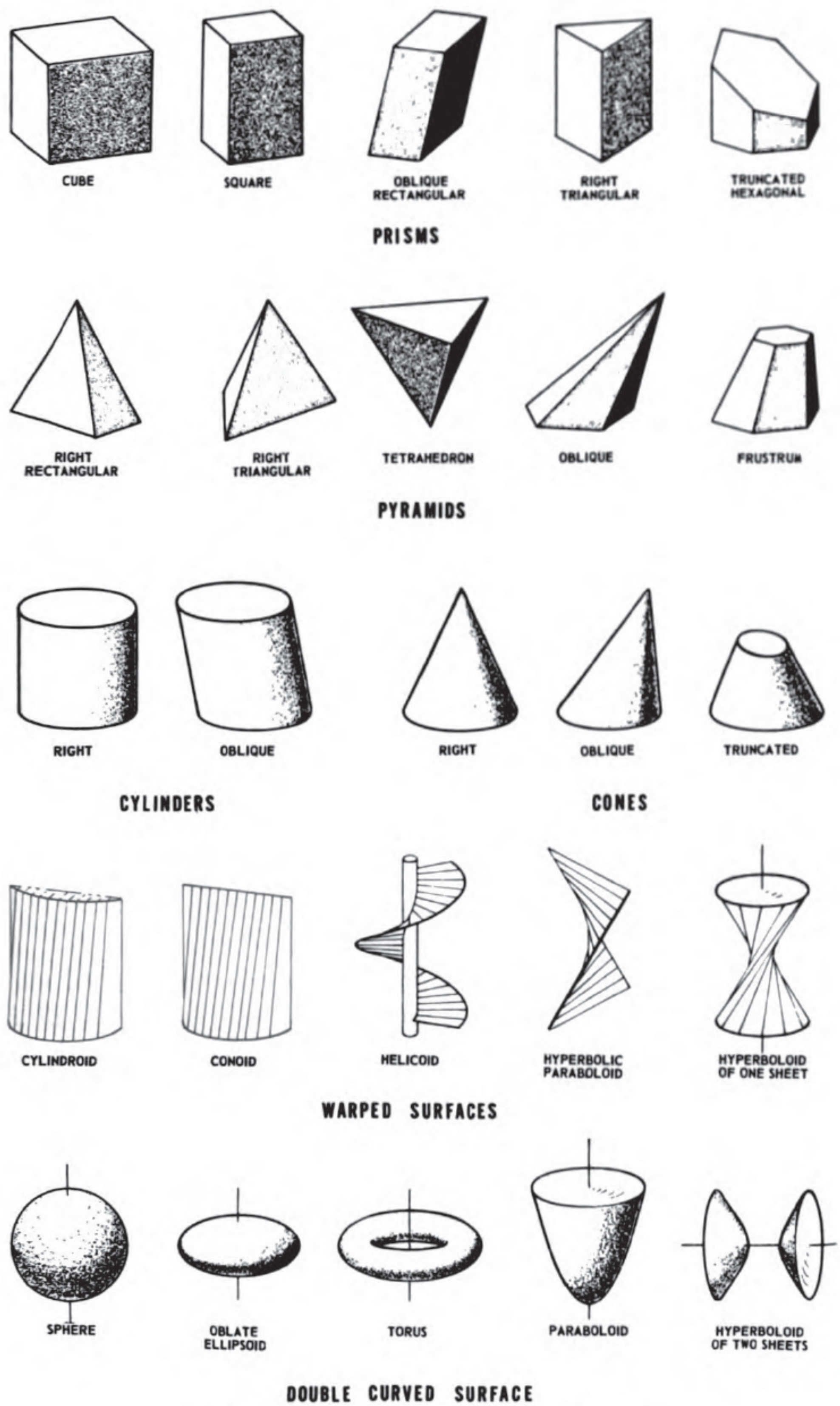


Figure 6–1.—Three-dimensional shapes.

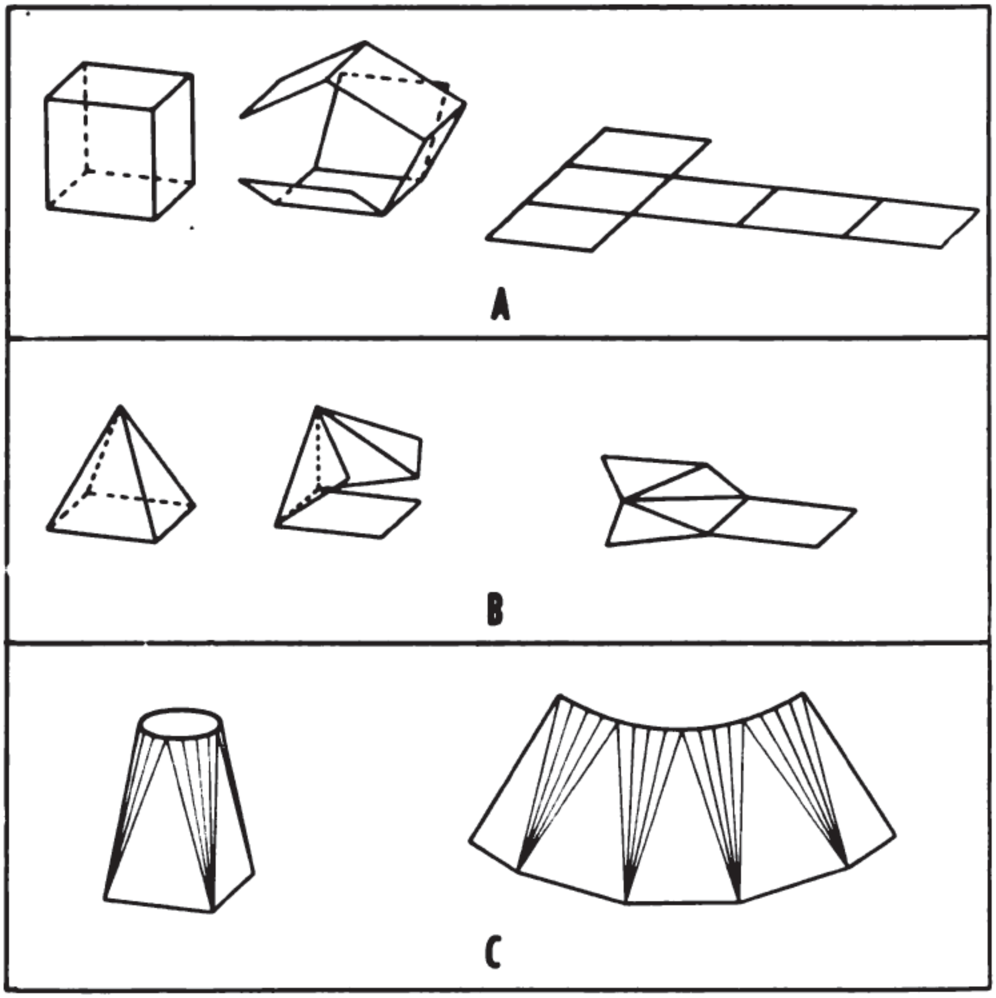


Figure 6–2.—A. Parallel development. B. Radial development. C. Development by triangulation.

In the Navy, development is used for many types of sheet metal work, such as ducts for heating, ventilating, and air conditioning systems, parts for boats, ships, and airplanes, and structural features involving the use of sheet metal or metal plates. A development may be drawn directly on the metal or a paper pattern may be made.

The developments worked out in this chapter do not include allowances for seams, because these vary according to the material used and its thickness. Considerable knowledge of shop work is necessary in order to choose the best type of seam for any particular piece and in order to cut the development out of the metal without errors and waste. Note that

most of the developments in this chapter provide for the seam to fall on the shortest side when there is a choice. When a number of pieces of similar shape are to be cut from one sheet of metal, the seam may be alternated from side to side in order for the pieces to fit together without much waste metal between them.

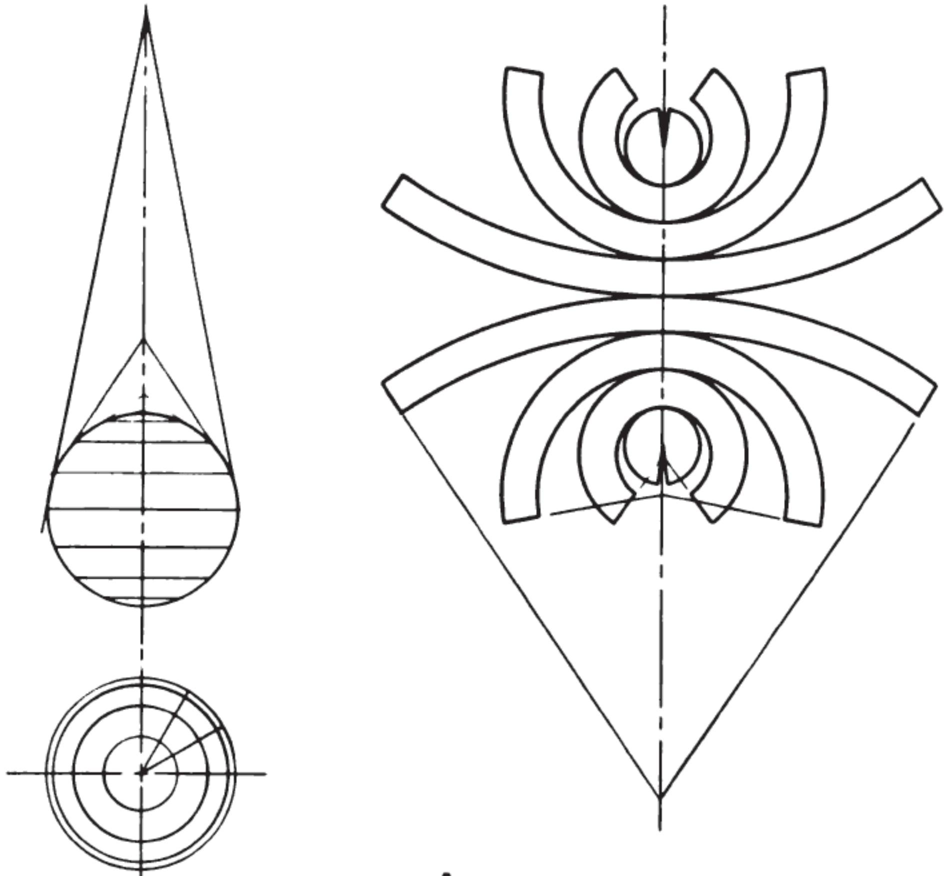
The three principal methods of developing the surface of three-dimensional objects are called PARALLEL DEVELOPMENT, RADIAL DEVELOPMENT, and TRIANGULATION. Parallel development is used for surfaces such as those of prisms or cylinders. (See fig. 6–2A.) Radial development is used for surfaces such as those of cones and pyramids, which may be said to be generated by a line of which one end remains fixed while the other end rotates about it. (See fig. 6–2B.) Triangulation is used for surfaces which do not lend themselves to either of the other two methods and to approximate the development of warped surfaces. (See fig. 6–2C.)

Double-curved surfaces, such as the surface of a sphere, may be developed approximately by several methods which you will probably never have occasion to use in the Navy but which are interesting in that the identical methods are applied in various map projections. A sphere may be cut into horizontal sections, or zones, which may be considered, and developed, as frustums of cones, as shown in figure 6–3A. A sphere may also be cut into equal meridian sections, called lunes, and these developed as if they were sections of cylinders. (See fig. 6–3B.)

PARALLEL DEVELOPMENT

The surfaces of prisms and cylinders are made up of parallel elements or of elements that can be treated as parallel elements. For example, in figure 6–4, the steps in developing a rectangular prism are illustrated.

1. In order to determine the length of all the edges of the prism, draw the front and top views in orthographic projection. (See fig. 6–4A.)



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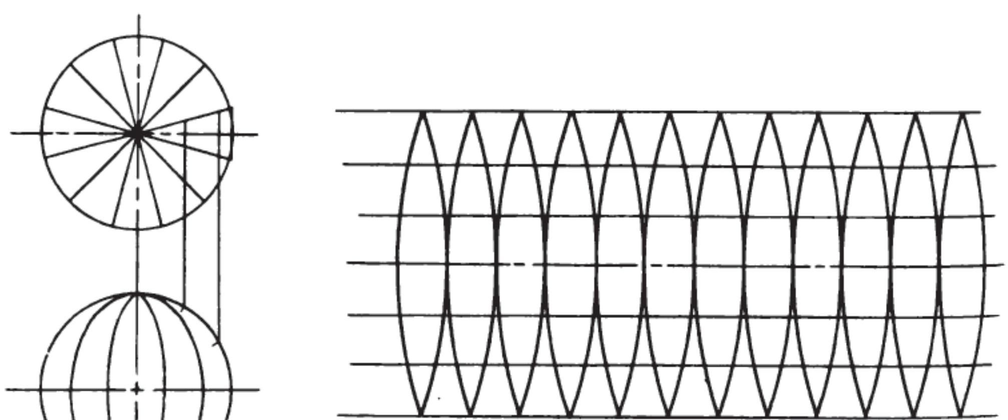

B

Figure 6–3.—Development of double-curved surfaces.

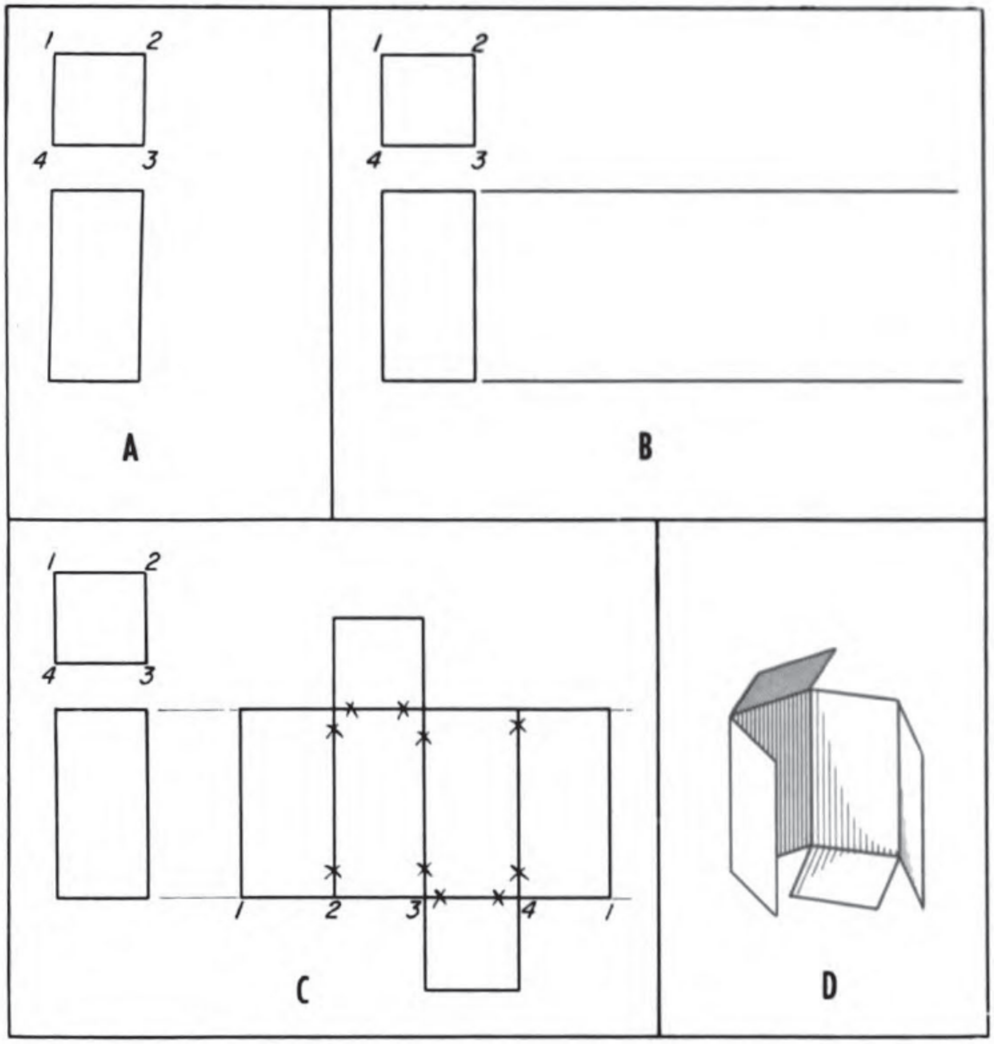

Figure 6–4.—Parallel development of a rectangular prism.

2. Draw the development to one side of the front view so that the dimensions of vertical elements on that view can be projected to the development as shown in figure 6–4B.

3. Transfer the dimensions of other elements from the top view. (See fig. 6–4C.) Notice that all bend lines are marked with crosses near their ends to distinguish them from outlines.

4. To check the drawing, measure the lines of edges which are to be joined as illustrated in the pictorial drawing in figure 6–4D. Such edges must correspond exactly.

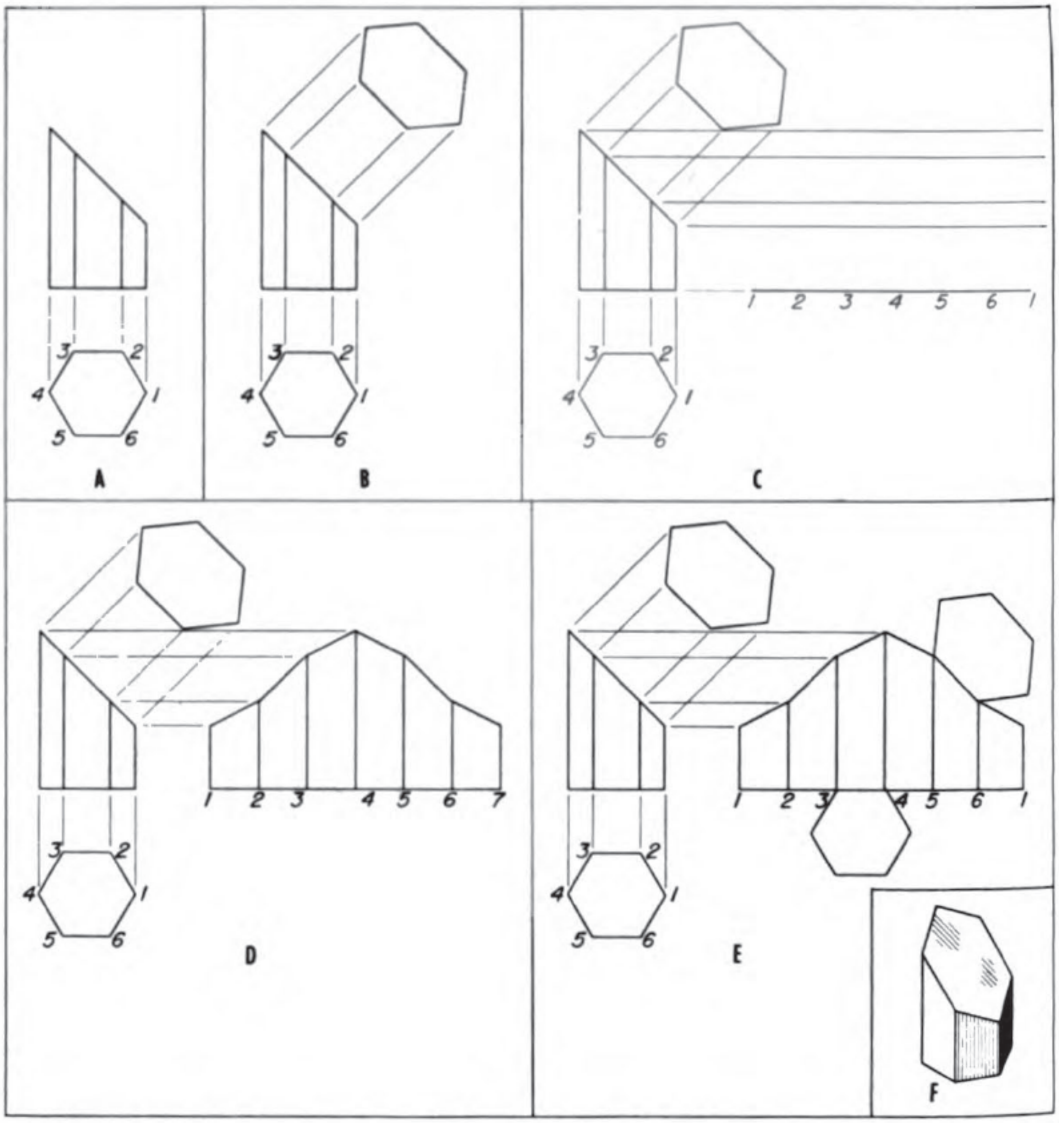

Figure 6–5.—Development of a truncated hexagonal prism.

In figure 6–5, the steps in the development of a truncated hexagonal prism are illustrated.

1. Draw a front view and a bottom view of the prism in orthographic projection. (See fig. 6–5A.)
2. Since the true shape of the slanting plane and the length of the lines of its edges are not shown in these views, draw an auxiliary view as shown in figure 6–5B. Note that it is not necessary to draw the entire prism in the auxiliary view, since only the dimensions of the plane surface are required.

3. Project the lines of the front view horizontally as the first step in constructing the development. (See fig. 6–5C.)
4. Number the points of intersection of planes on the bottom view, and mark off line segments of the same length on the base line of the development.
5. Erect vertical lines from these numbered points to intersect the lines projected from the front view of the prism. (See fig. 6–5D.) These intersections mark the corners of the prism.
6. Connect the intersection points with straight lines.
7. Draw the bottom of the prism attached to one of the sides at the base line. Draw the slanting plane at the top of the prism, as it is shown in the auxiliary view, attached to one of the sides. (See fig. 6–5E.)
8. Check all measurements of edges to be joined as shown in the pictorial drawing in figure 6–5F, in order to be sure that they will coincide exactly.

The development of a truncated cylinder, illustrated in figure 6–6, follows a very similar procedure. The cylinder is considered to be a prism with an infinite number of sides. In developing a cylinder, the number of sides must necessarily be limited, but the greater the number of sides, the more accurate the development is likely to be.

1. To develop one-half of a two-piece elbow, first draw a front and bottom view of that piece in orthographic projection. (See fig. 6–6A.) Since the elbow does not require an end piece, it is not necessary to draw an auxiliary view showing the true shape of the ellipse formed by the cutting plane at the top of the cylinder.
2. Divide half the circumference of the circle into a number of equal parts. The parts should be small enough so that, when a straight line is drawn between division points, it will approximate the length of the arc. Project lines from these points to the front view, as shown in figure 6–6B. The resulting parallel lines on the front view are called ELEMENTS.

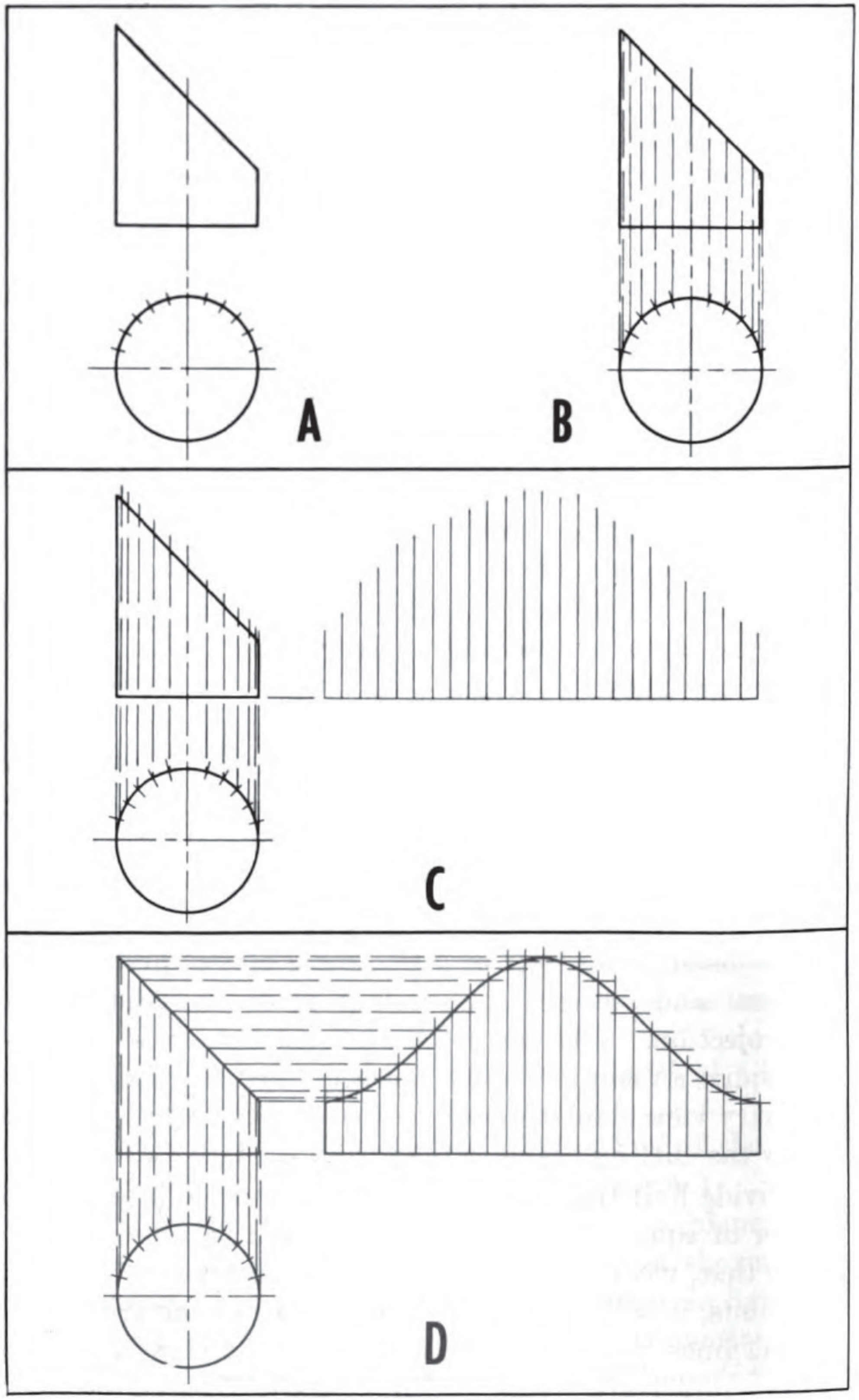

Figure 6–6.—Development of a truncated cylinder.

3. Lay off the base line, called the STRETCH-OUT LINE, of the development. The length of this line may be calculated as π times the diameter of the cylinder (3.1416 x D).
4. Divide the stretch-out line into twice the number of equal parts as the number on the half circle of the orthographic view. (See fig. 6–6C.)
5. Erect perpendiculars at each point, as shown in figure 6–6C.
6. Using a T-square, project the lengths of the elements on the front view to the development. (See fig. 6–6D.)
7. Using a french curve, join the resulting points of intersection in a smooth curve.

When the two pieces of the elbow are identical, it is only necessary to make one pattern.

When a four-piece elbow is to be drawn, the same steps are followed to produce as many developments as may be required. The orthographic view may be drawn of the whole elbow and the developments drawn beside each separate piece, as illustrated in figure 6–7. Here only one end and one middle development are drawn, since the other two pieces are identical with these.

Intersections

When two pieces, such as two cylinders or a cylinder and a prism, intersect, it is necessary to determine the exact points of intersection in order to make developments for the pieces that will fit together without gaps or unnecessary overlaps. These intersections are determined by carefully drawing the elements intersecting on orthographic views and then projecting or transferring these intersection points to the developments. In figure 6–8, for example, the steps in making developments for a T-joint are illustrated. The T-joint consists of two cylinders with equal diameters which intersect at right angles.

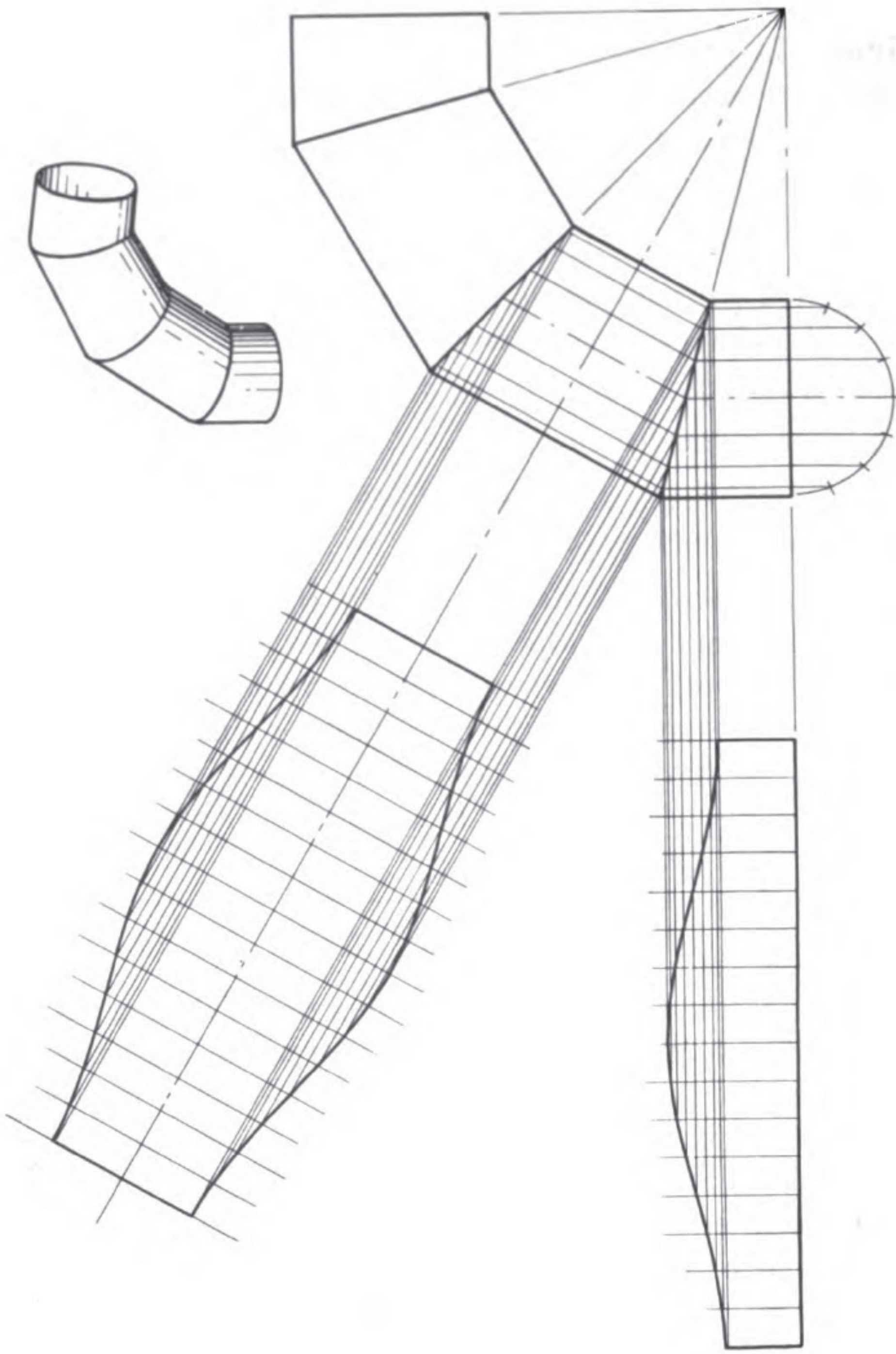

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Figure 6–7.—Developments for a four-piece elbow.

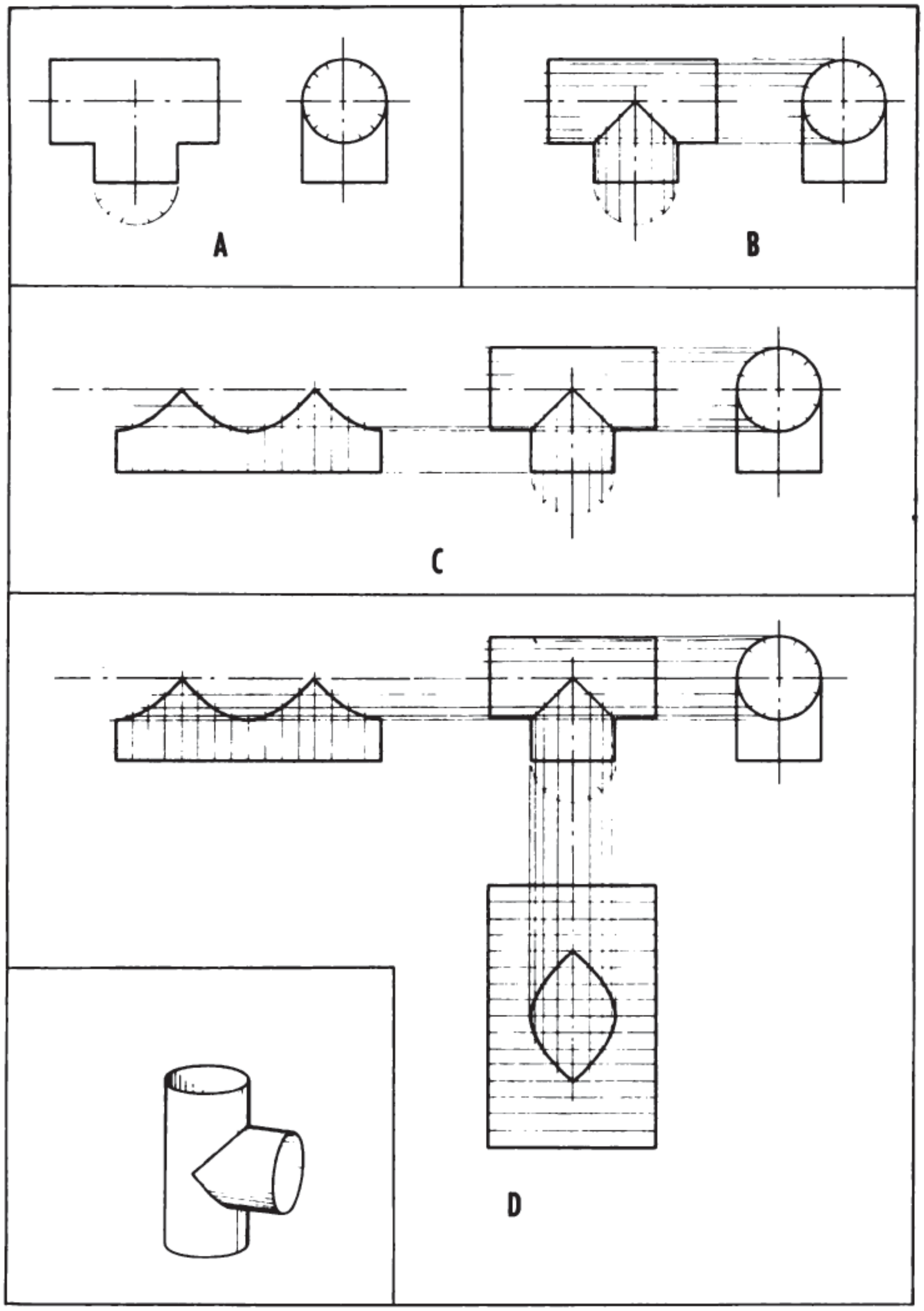

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Figure 6–8.—Development of a T-joint composed of cylinders of equal diameter.

1. Draw a front view and a side view of the T-joint. A bottom view representing the open end of the other cylinder might also be drawn. However, since this cylinder is perfectly round, a semicircle may be drawn attached to the front view and the division points for the elements located on it. (See fig. 6–8A.)
2. Draw equally spaced divisions to locate the elements and project these division points to both cylinders. The points where the elements of one cylinder intersect those of the other define the intersection of the two cylinders. (See fig. 6–8B.)
3. Draw the surface pattern of the projecting pipe at one side of the orthographic view so that the length of each element can be projected from the front view, as shown in figure 6–8C.
4. Draw the surface pattern of the cross pipe below the front view, projecting lines down from the branch pipe to locate the opening for it, as shown in figure 6–8D.

When the T-joint is made of two cylindrical pipes of unequal diameter, the procedure differs slightly.

1. Draw the orthographic views.
2. Divide the smaller diameter branch pipe into equal parts, and draw the elements on this pipe in both views, as shown in figure 6–9A. The length of each element is shown in the side view.
3. Project lines from the upper end of each element in the side view to the front view, as shown in figure 6–9B. The intersections of these lines with the vertical lines drawn on the branch pipe define the intersection of the two pipes.
4. Draw the line of intersection on the front view.
5. Draw the surface pattern of the branch pipe to the left, continuing the projection lines to locate the ends of elements. (See fig. 6–9C.)
6. Draw the surface pattern of the larger diameter main pipe beneath the front view, projecting lines down from the branch pipe to locate the opening for it, as shown in figure 6–9D.

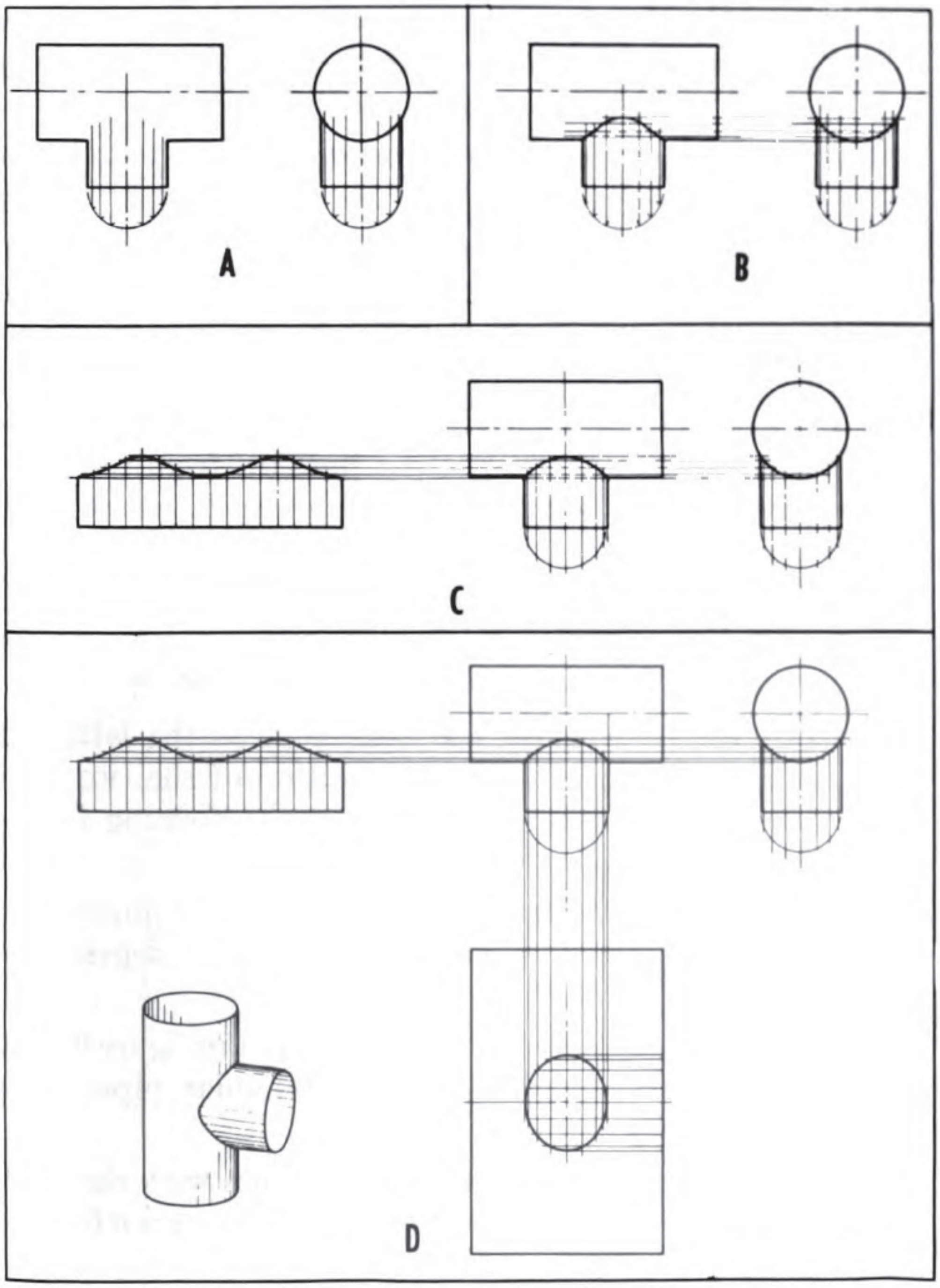

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Figure 6–9.—Development of a T-joint with two cylindrical pipes of unequal diameter.

Figure 6–10 illustrates the steps in drawing a round pipe joint made up of two cylindrical pipes of unequal diameter which intersect at an angle other than 90 degrees.

1. Draw the front and top orthographic views. The ellipse formed by the top of the branch pipe may be omitted at this point and drawn later.
2. Draw the elements on the branch pipe in both views. (See fig. 6–10B.)
3. Project lines down from the left end of each element in the top view to the corresponding element in the front view, and draw the line of intersection. (See fig. 6–10C.)
4. Draw the ellipse formed by the end of the branch pipe in the top view, by projecting lines up from the upper end of each element in the front view to the corresponding element in the top view. (See fig. 6–10D.)
5. Draw the pattern of the branch pipe to the right and perpendicular to the pipe as it appears in the front view, as shown in figure 6–10E.
6. Draw the pattern for the main pipe to the left, with lines projecting from the intersection of the two pipes on the orthographic view to locate the opening for the branch pipe. (See fig. 6–10F.)

When a pipe joint consists of a rectangular pipe intersecting a round pipe at an angle other than 90 degrees, the procedure is similar.

1. Draw the orthographic views, as shown in figure 6–11A, dividing the upper surface of the rectangular pipe in the top view by equally spaced elements.

2. The points of intersection of these lines with the circle are then projected down to the upper and lower surfaces of the branch pipe in the front view. (See fig. 6–11B.)

3. Develop the surface pattern of the rectangular pipe perpendicular to it in the front view, as shown in figure 6–11C.

4. Draw the surface pattern of the round pipe, with the opening for the rectangular pipe, to the side of the front view, as shown in figure 6–11D.

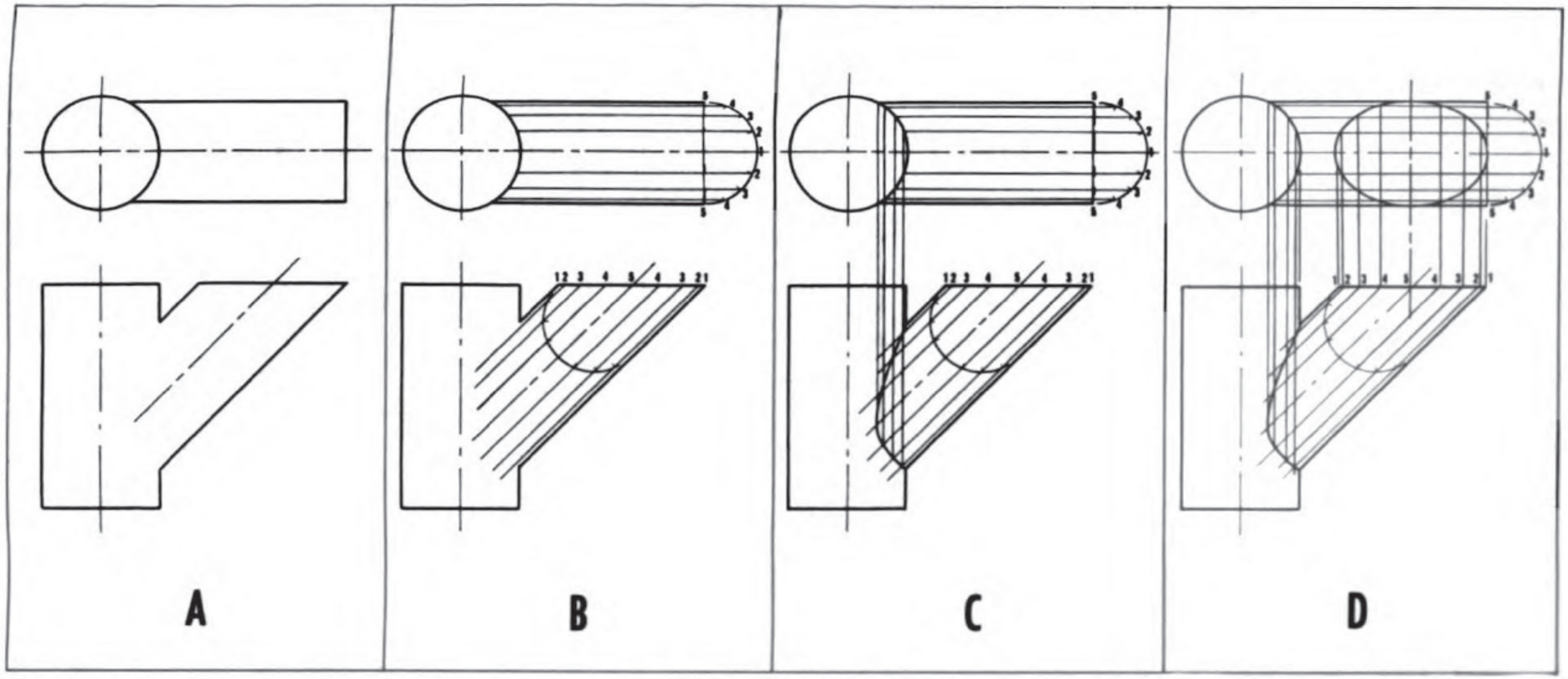

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Figure 6–10.—Development of a round pipe joint made of two cylindrical pipes of unequal diameter intersecting at an angle other than 90 degrees.

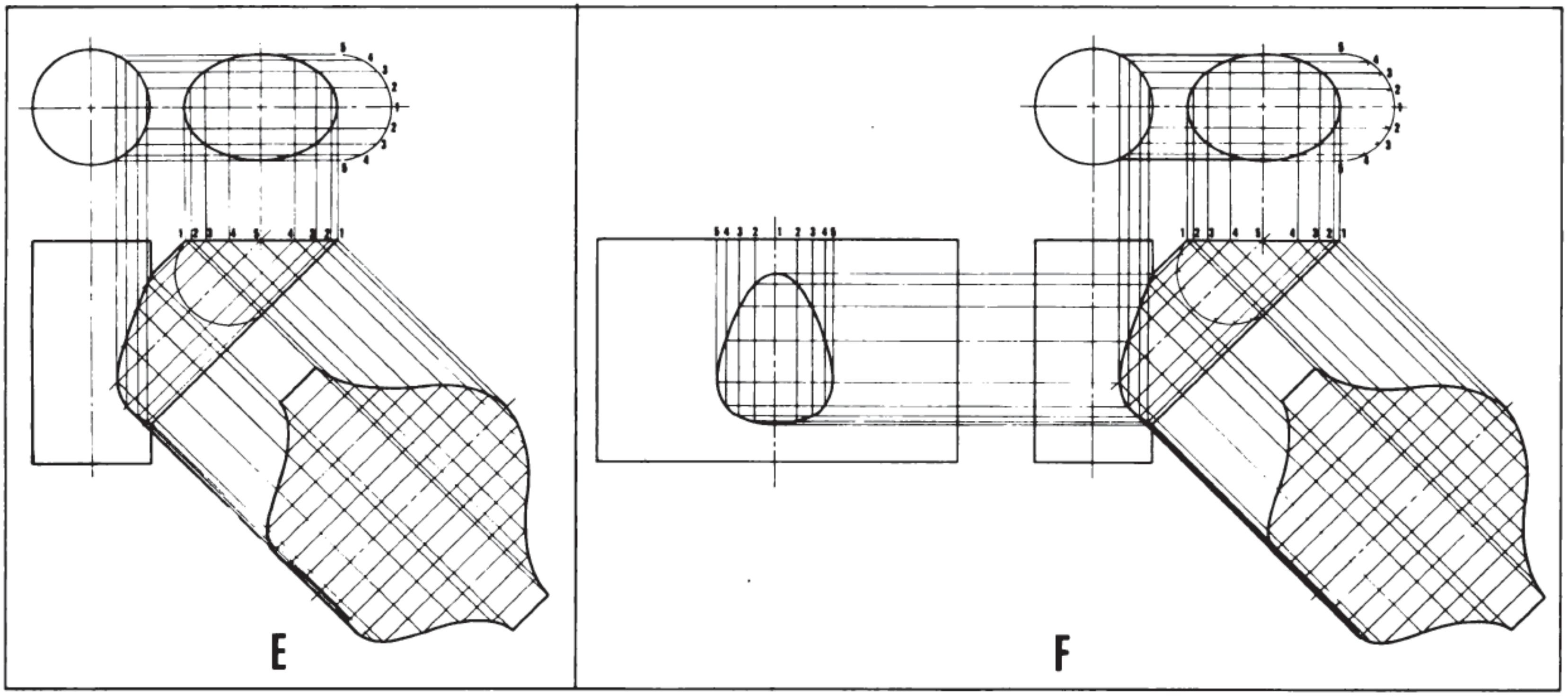

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Figure 6—10.—Development of a round pipe joint made of two cylindrical pipes of unequal diameter intersecting at an angle other than 90 degrees—Continued.

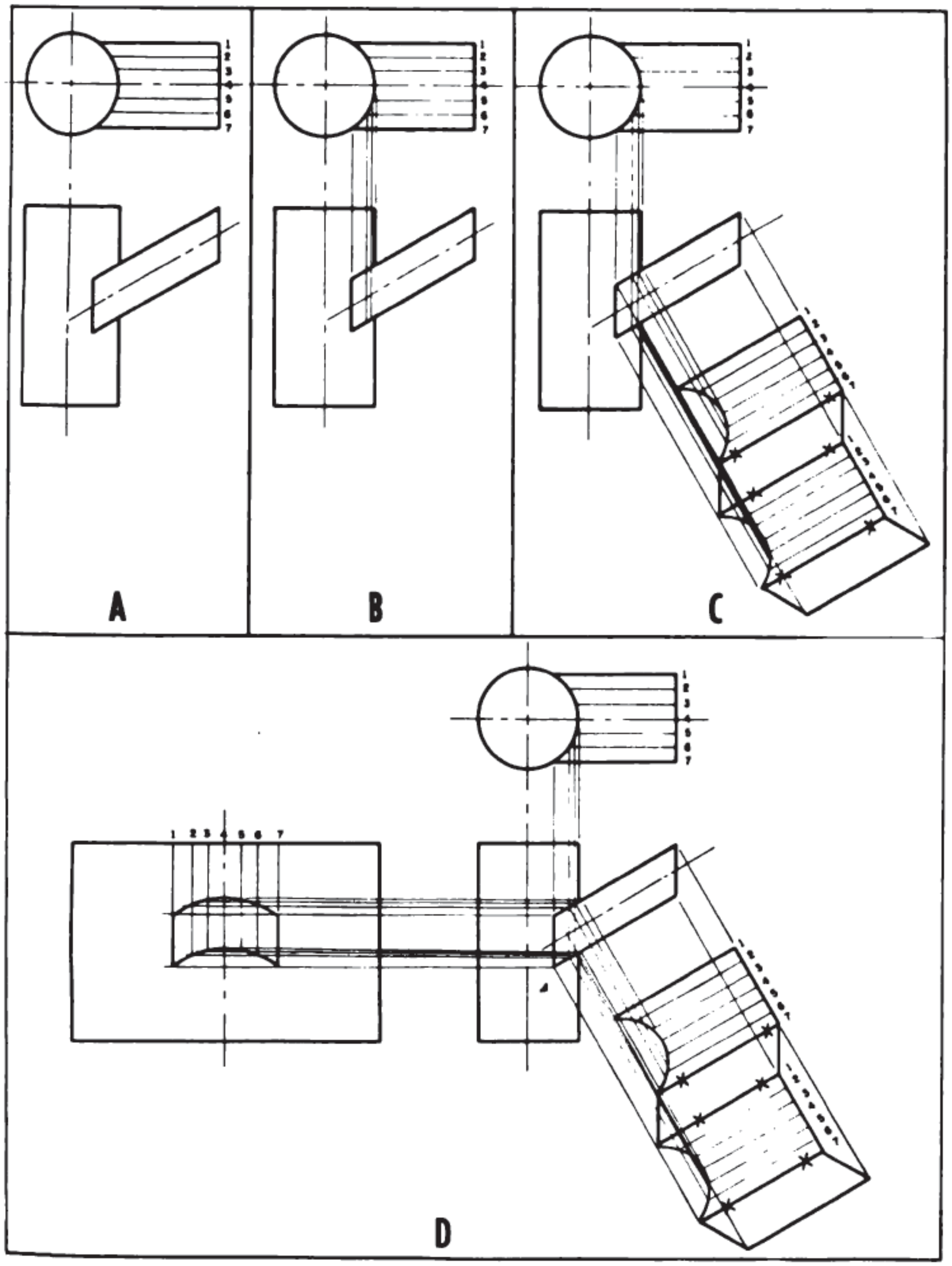

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Figure 6–11.—Development of a pipe joint in which a rectangular pipe intersects a round pipe at an angle other than 90 degrees.

RADIAL DEVELOPMENT

The sides of a pyramid and the elements of a cone meet at a point called the vertex or apex. These same lines meet at a point in the development of a pyramid or cone and are said to radiate from this point. Consequently, the method of developing pyramids or cones is called radial development.

In radial development, the same general procedures are followed as those used in parallel development, except that since the slanting lines of pyramids and cones do not always appear in their true lengths on the orthographic views, certain other procedures must be followed in order to determine these true lengths. To find the true lengths of these edges, the pyramid may be rotated so that some of the edges appear in their true lengths in the views, as shown in figure 6–12B. In this case, the lines which appear as horizontal lines in the top view are shown in outline and in their true-length in the front view. In other words, WHEN A LINE APPEARS AS HORIZONTAL OR AS A POINT IN THE TOP VIEW, THE CORRESPONDING LINE IN THE FRONT VIEW IS ITS TRUE LENGTH. Conversely, WHEN A LINE APPEARS AS HORIZONTAL IN THE FRONT VIEW, THE CORRESPONDING LINE IN THE TOP VIEW IS ITS TRUE LENGTH.

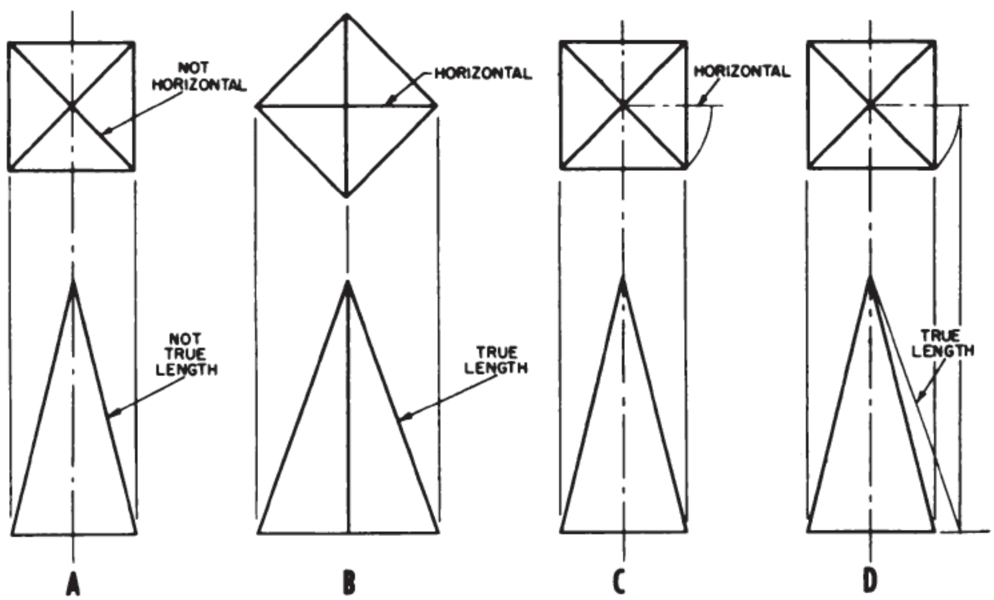

Figure 6–12.—Methods of finding the true length of a line in radial development.

Usually, instead of rotating the whole pyramid, the line of the edge itself may be simply rotated into the horizontal on a conventional orthographic view. For example, in figure 6–12C, the line of an edge from apex to base as it appears in the top view is used as the radius for an arc to the horizontal. The point of intersection of the arc with the horizontal is projected to the front view and a true-length line for that edge drawn, as shown in figure 6–12D.

The steps for developing a truncated pyramid are illustrated in figure 6–13. This is a transition piece for con-

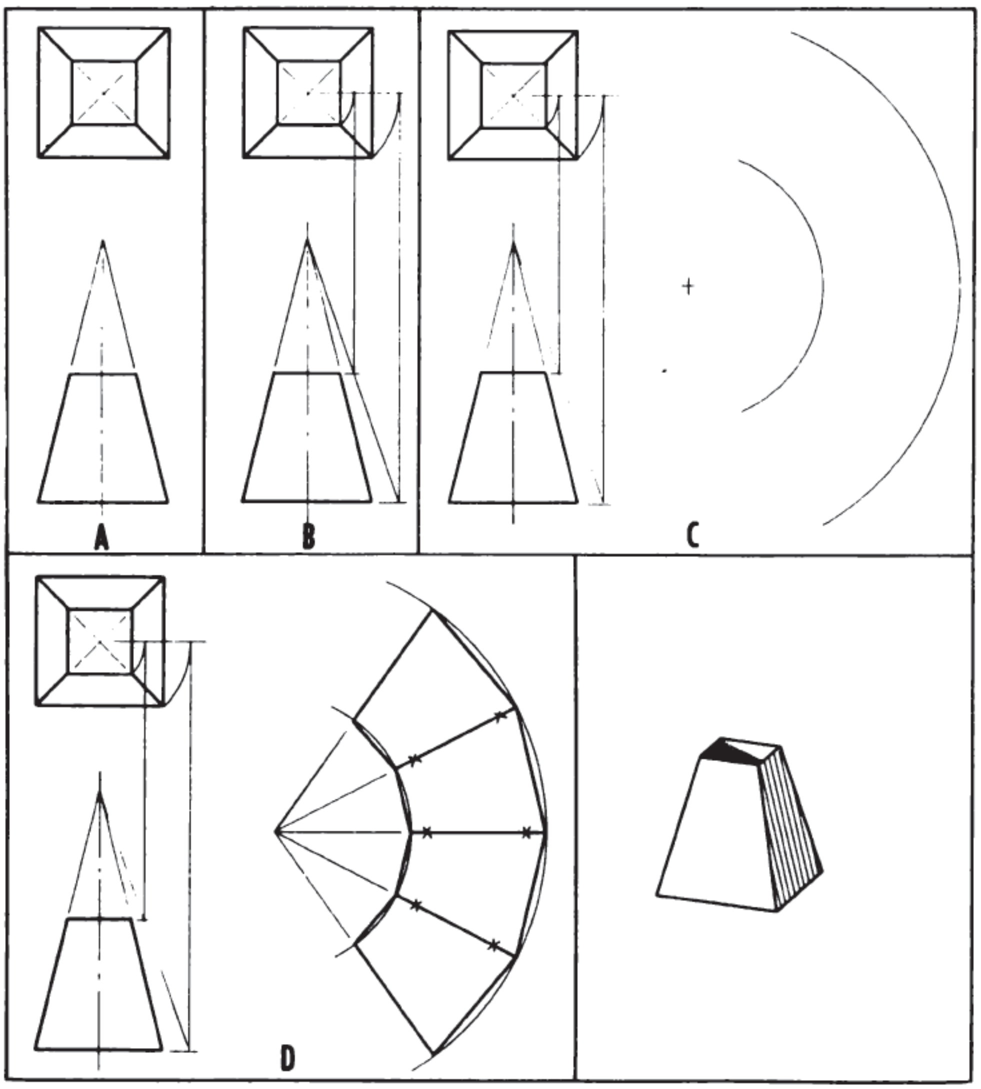

Figure 6–13.—Development of a truncated pyramid.

necting a large square pipe with a smaller one. Normally the square ends would be terminated in square collars which would also be developed.

1. Draw the orthographic views, completing the lines of the sides to the apex.
2. Rotate the line of one edge in the top view to the horizontal and project it to the front view. (See fig. 6–13B.)
3. Draw an arc with a radius equal to the length of this true-length line plus its extension to the apex of the pyramid, and a second arc defining the upper limit of the true-length line, as shown in figure 6–13C.

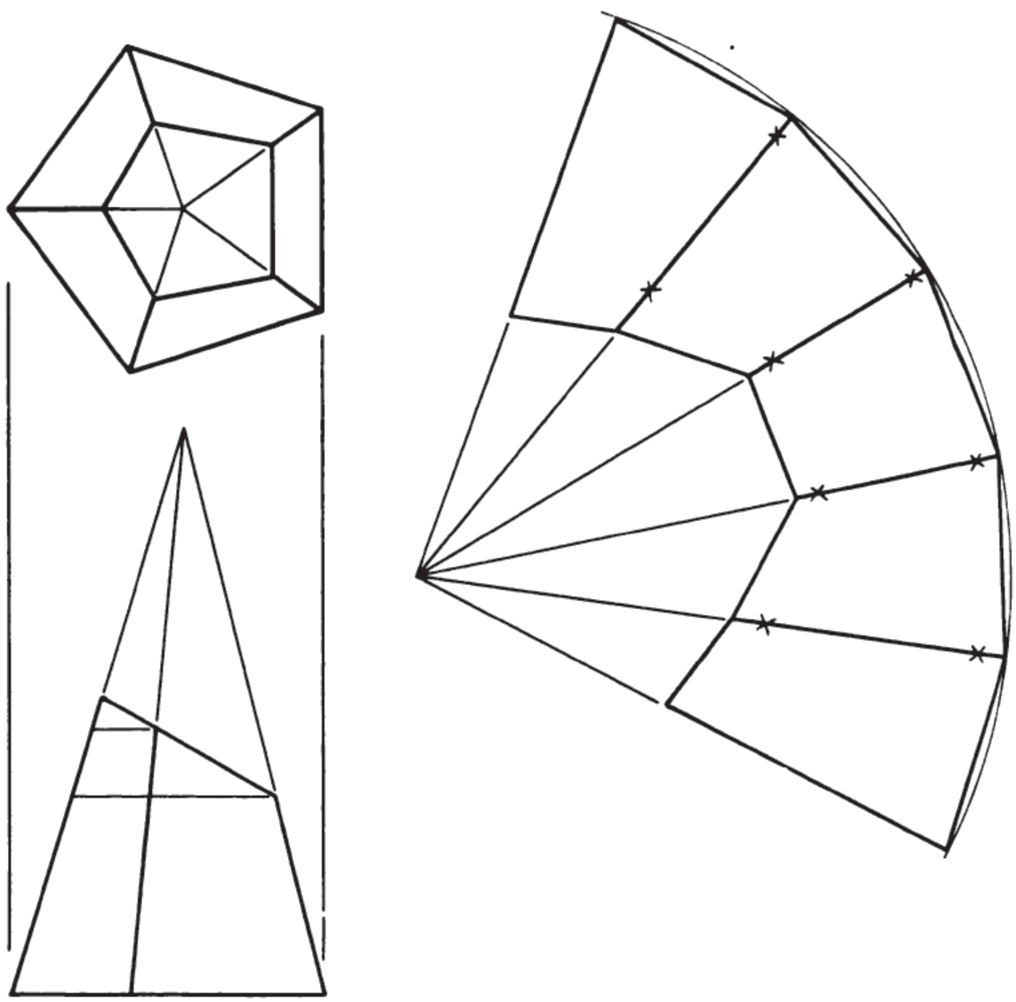

Figure 6–14.—Development of a truncated pentagonal pyramid with the upper corners cut by a slanting plane.

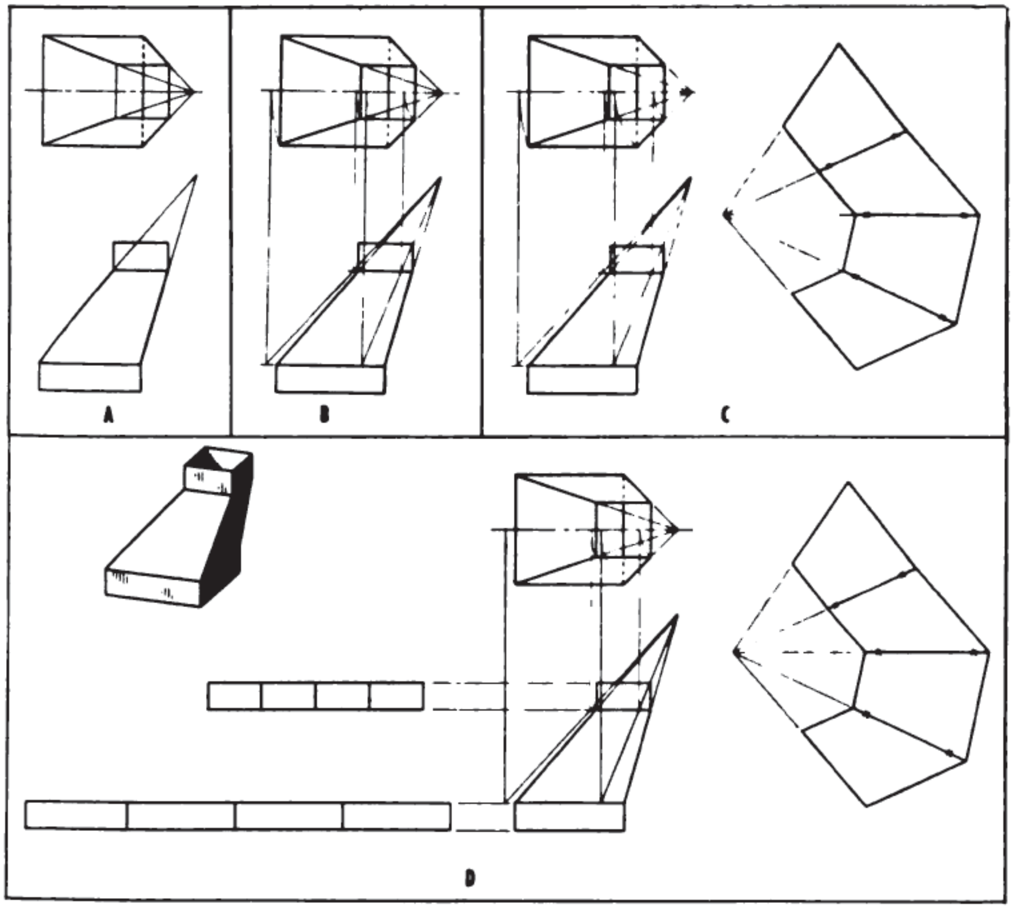

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Figure 6–15.—Development of an offset transition piece.

4. Step off lengths along these arcs equal to the sides of the pyramid. (See fig. 6–13D.)
5. Connect these points successively with each other and also connect them by light lines with the vertex, as shown in figure 6–13D.

To develop a truncated pentagonal pyramid like that shown in figure 6–14, the same general steps are followed. However, since one lateral edge appears in its true length in the front view, the limits of the other edges may be projected onto the line of this edge in order to determine the true lengths. The length of each edge is then measured, and this measurement transferred to the development.

Figure 6–15 shows the development of an offset transition

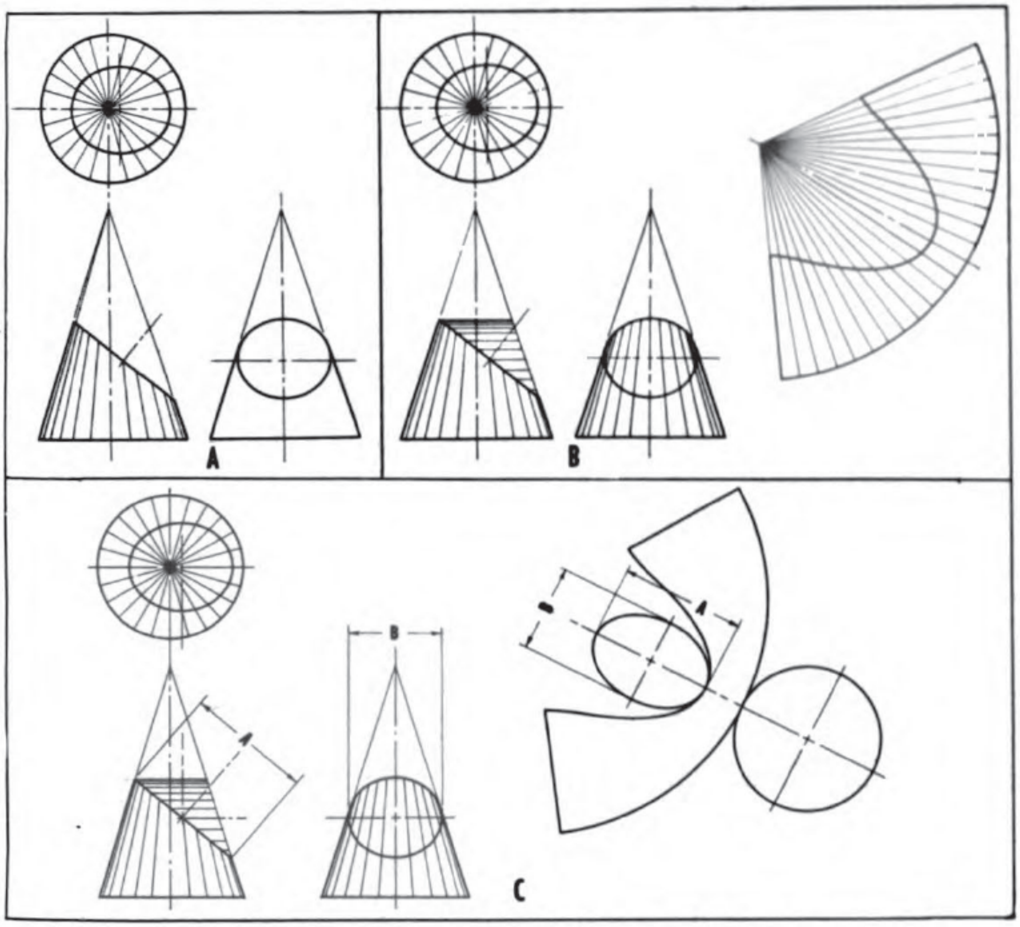
piece. It is called OFFSET because the center of one end is not in line with that of the other end. The three parts consist of an upper section and a lower section, which are truncated rectangular prisms, and a third section, which is a truncated oblique pyramid.

1. Draw the orthographic views, extending the lines of the sides of the pyramid to its apex in both views.
2. Rotate the lines of the sides to the horizontal in the top view, project the points thus located to the front view, and draw the true-length lines. (See fig. 6–15B.)
3. At one side of the views, develop the surface pattern of the oblique square pyramid. Construct one triangle at a time, taking the length of the three sides of each triangle from the views. (See fig. 6–15C.) Locate and draw the upper edges to complete the pattern.
4. Draw the surface patterns of the upper and lower prisms, as shown in figure 6–15D.

The development of a cone is similar. It is considered to be a pyramid with an infinite number of sides. In practice, of course, the number of sides must be limited. Elements representing these sides are drawn on the orthographic views and projected to the development. The steps in developing a truncated right cone are illustrated in figure 6–16.

The right cone has a center line which is perpendicular to its base. Thus the elements on a right cone are all the same length. The true length of these elements is shown by those which fall to the extreme right and left in the front view, since these elements are horizontal lines in the top view. The cone in figure 6–16 is cut by a slanting plane. Therefore the termination points of the elements between the two outside elements must be projected to one of the outside lines in order for their true length to be determined.

1. Draw the orthographic views, including either a side view, as shown in figure 6–16A, or an auxiliary view of the ellipse which is formed by the slanting plane. Note that the center of the ellipse must be determined since it does not fall on the center line of the cone. This center



Courtesy Columbia Technical Institute

Figure 6–16.—Development of a truncated right cone.

point is projected to the side view and defines the length of the minor axis of the ellipse. The length of the major axis is defined by the length of the slanting line in the front view.

2. Develop the surface pattern of the cone, using the length from the apex to the base as a radius for drawing the arc. Step off on this line the equally spaced divisions of the base. Then measure each element individually and transfer this measurement to the development. The ends of each of these elements define the curve of the upper edge of the peripheral surface. (See fig. 6–16B.)
3. Draw the circle of the surface of the base and the ellipse of the top surface attached to the peripheral surface as shown in figure 6–16C.

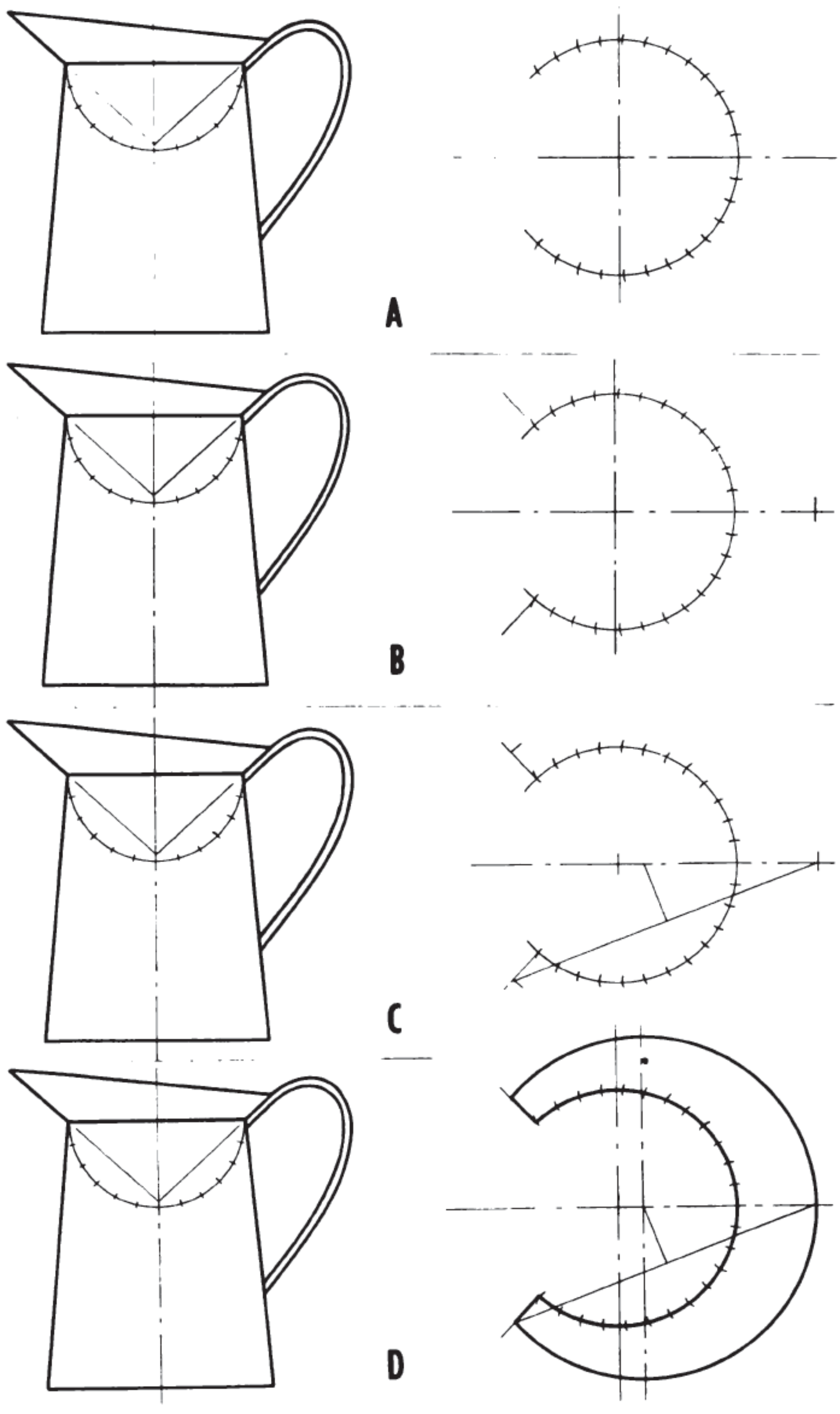


Figure 6–17.—Development of a pouring lip.

In figure 6–17, the pouring lip on the round measure is a truncated portion of an inverted cone. The lower end is cut by a plane parallel to the base and the upper end is cut by a slanting plane. The same procedures may be used to find the elements on this lip as those described in connection with the truncated cone shown in figure 6–16. However, a shorter method may also be used to develop the surface pattern of the lip.

1. Draw an orthographic view, and locate the apex of the inverted cone.
2. Draw a semicircle attached to the lower edge of the pouring lip, and divide this into equal spaces. (See fig. 6–17A.)
3. As the first step in developing the surface pattern, draw an arc with a radius equal to the line from the apex of the angle to the lower edge of the lip along one of the true-length lines. (See fig. 6–17A.)
4. Draw a center line through this arc, and step off the same number of equal spaces on each side of this line as appear on the semicircle in the front view.
5. From the final steps on each side, draw lines the distance of the short side of the lip, as shown in figure 6–17B, and also locate a point beyond the arc on the center line at a distance equal to the long side of the lip in the orthographic view.
6. Draw a line from this point to the outer edge of the lip at the seam as shown in figure 6–17C.
7. Bisect this line, and draw a line perpendicular to it which intersects the center line.
8. With this intersection as the center and with a radius equal to the distance from this center to the points already located on the outer edge of the lip, draw an arc describing this outer edge. (See fig. 6–17D).

TRIANGULATION

Triangulation is slower and more difficult than parallel line or radial development, but it is more practical for

many types of figures. Also it is the only method by which the developments of warped surfaces may be approximated. In development by triangulation, the piece is divided into a series of triangles as in radial development. However, there is no one single apex for the triangles. The problem, therefore, becomes one of finding the true lengths of the varying oblique lines. This is usually done by drawing a TRUE-LENGTH DIAGRAM.

Figure 6–18 illustrates the steps in the triangulation of a warped transition piece joining a large square pipe and a smaller round pipe.

1. Draw the top and front orthographic views.
2. Divide the circle in the top view into a number of equal spaces and connect the division points with the corners of the square, as shown in figure 6–18B.
3. Transfer the division points to the front view, and draw the elements. Some of the triangles are slightly curved, but they may be considered as flat.
4. Now the true length of each of these elements may be found by drawing a right triangle with a base equal to the length of an element on the top view and with an altitude equal to the altitude of the corresponding element on the front view. The hypotenuse of the triangle is the true length of the element. In figure 6–18C, the true-length diagram consists of only three right triangles. Since the piece is symmetrical, a number of the elements are the same length.
5. Draw the surface pattern, constructing one triangle at a time. (See fig. 6–18D.) Note that the seam may be along one of the elements, or it may be on the center line through one of the large triangles in which case its true length is shown by either of the outside lines on the front view.

Figure 6–19 shows the steps in developing a rectangular transition piece which is not a true pyramid because the extended lateral edges would not meet at a common vertex.

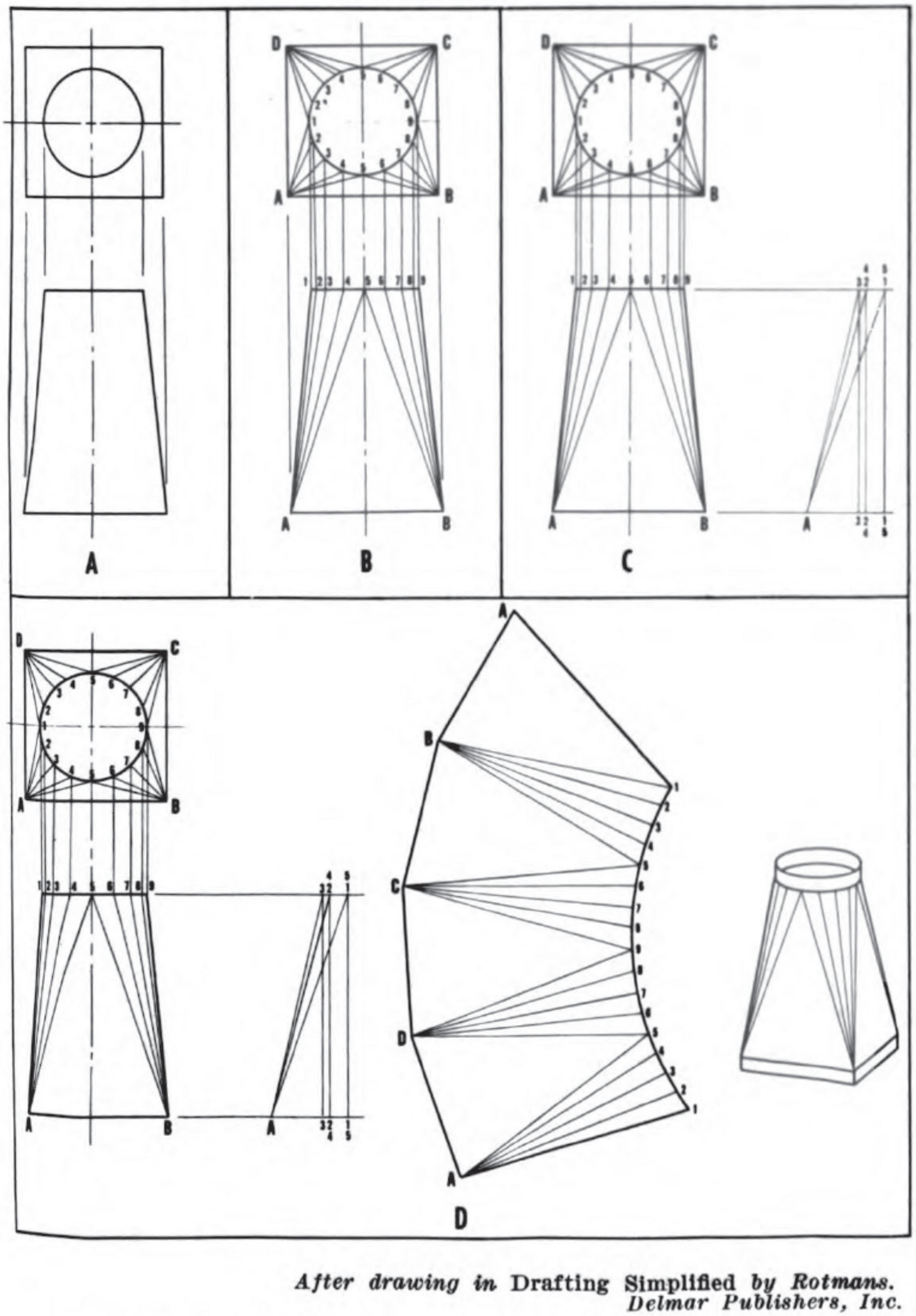


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Figure 6–18.—Development by triangulation of a transition piece.

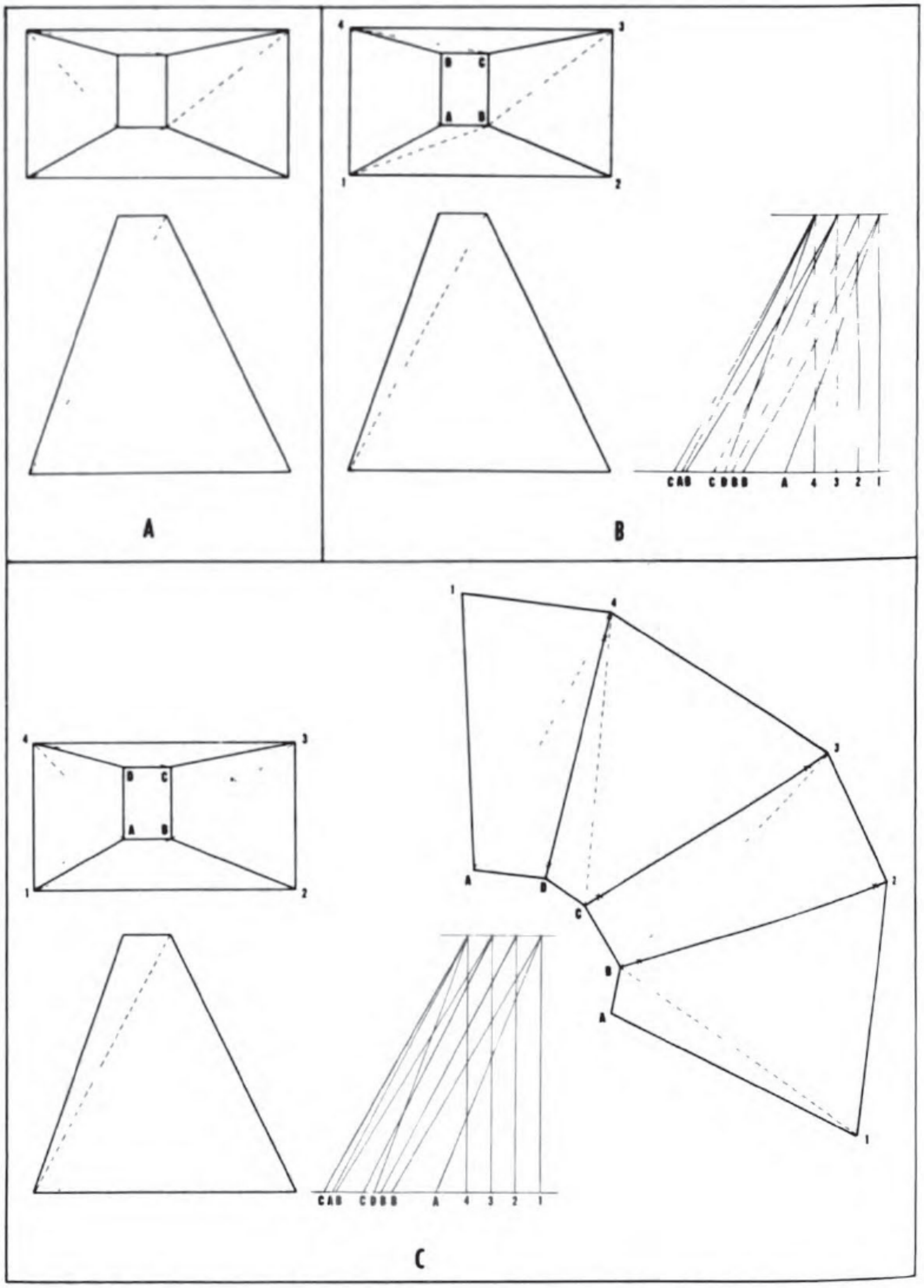

Figure 6–19.—Development of a rectangular transition piece which is not a true pyramid.

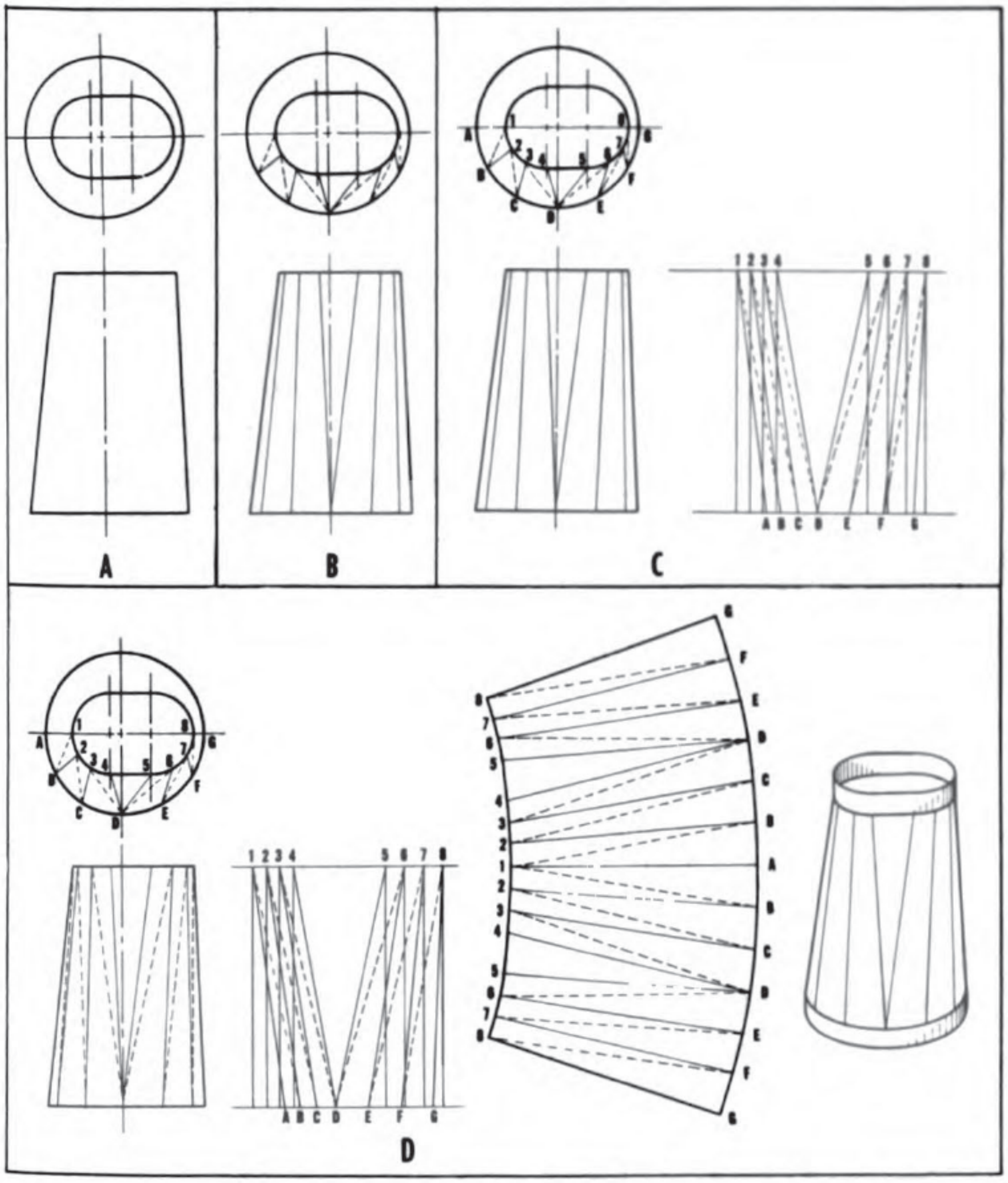

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Figure 6–20.—Development of a warped transition piece.

This may best be developed by drawing diagonals which split the sides into two triangles. These diagonals are usually drawn as dotted lines to differentiate them from other elements. Then the true length of each element is found, and the surface pattern developed by constructing each triangle in turn. To find the true-length lines, a true-length diagram is drawn.

1. Draw the orthographic views with the bend lines and the diagonals. (See fig. 6–19A.)
2. Draw a true-length diagram of these elements. (See fig. 6–19B.)
3. Draw the surface pattern by constructing one triangle at a time. (See fig. 6–19C.)

The fitting in figure 6–20 has a warped surface. Its base is round and its top is oblong. The method for development consists of dividing the surface into quadrilaterals of approximately the same size, and then drawing a diagonal across each of these to produce two triangles. When the true lengths of these elements have been found, the surface pattern may be drawn, triangle by triangle.

1. Draw the top and front orthographic views.
2. Divide the circle of the base into a number of equal spaces and the arcs at the ends of the oblong into half as many. Since the transition piece is symmetrical on a central axis, this may be done on only half of the top view. Connect these division points as shown in figure 6–20B. Use dotted lines for the diagonals to differentiate them.
3. Project the division points to the front view, and draw the elements there.
4. Draw the true-length diagram for the elements. (See fig. 6–20C.)
5. Draw an approximation of the surface pattern of the warped surface by constructing one triangle after another. (See fig. 6–20D.)

QUIZ

1. Name four types of surfaces.
2. What is meant by the term DEVELOPING A SURFACE?
3. What are the three principal methods of developing the surface of three-dimensional objects?
4. For what surfaces is parallel development used?
5. For what surfaces is radial development usually used?
6. For what surfaces is triangulation used?

7. How may bend lines be indicated on the development of a surface?
8. When the drawing of the surface pattern is finished what edges must be checked and why?
9. How are the intersection lines of two pieces, such as two cylinders or a cylinder and a prism, determined?
10. (a) In radial development, how can you tell whether a line appears in its true length on the front orthographic view? (b) On the top orthographic view?
11. To bring a line into the horizontal in a view, what method is usually used?
12. When one edge of one side of a truncated right equilateral pyramid appears in its true length in the front view, what method may be used to determine the true length of the other edges?
13. What does the word OFFSET mean?
14. Since development by triangulation is slower and more difficult than parallel line or radial development, why is it used?
15. In development by triangulation, what two methods for finding the true lengths of lines may be used?
16. (a) In a true-length diagram, how is the length of the base line of each right triangle determined? (b) The altitude of the triangle? (c) The hypotenuse?

CHAPTER 7

HEATING, VENTILATING, AND AIR CONDITIONING

INTRODUCTION

Although our bodies can and do adjust themselves to many different atmospheric conditions, the zone of greatest comfort and efficiency has been found to be roughly in the vicinity of 70 degrees Fahrenheit with a relative humidity of 50 percent and with an air movement of 15 to 25 feet per minute. The temperature range of the comfort zone is slightly higher in warm weather than in cold. A relative humidity of 50 percent means that the air contains half as much moisture as the maximum it is capable of absorbing. Besides providing more comfortable living conditions, the regulation of atmospheric conditions is often necessary for the preservation or the proper functioning of equipment.

The maintenance of any required atmospheric temperature in an enclosure usually involves either supplying heat to compensate for heat loss or removing heat by mechanical cooling to compensate for heat gains. In the United States, heat is measured in British thermal units, written BTU. A single BTU is the heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit. Heat gains or losses in an enclosure are influenced by such factors as the temperature outside, the material and thickness of the walls, ceiling, etc., the amount of sunlight falling on them, and the amount of heat given off in the enclosure by humans and by mechanical devices.

For heating barracks and other large buildings, the Navy uses standard heating systems such as steam radiators, hot water radiators, or, in some instances, circulated warm air. Different installations vary somewhat in detail. For example, a steam heating system may be single-pipe or two-pipe. The condensate may be returned to the boiler by gravity or by means of a pump; or operating pressure in one system may be quite different from that of another. Hot

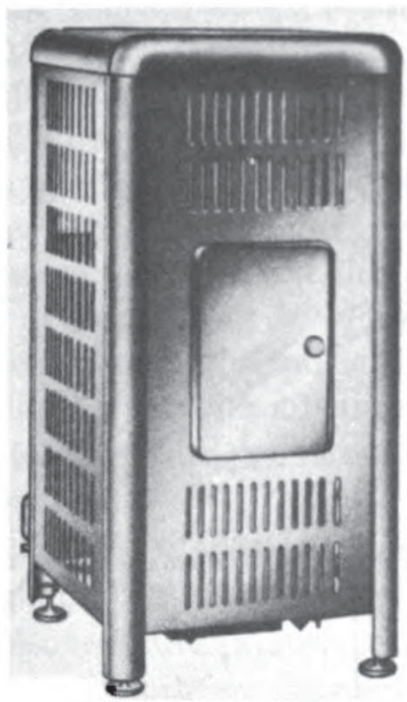


Figure 7–1.—Oil-fired space heater.

water systems vary in such things as gravity circulation or forced circulation, methods of connecting radiators, and methods of eliminating air from the system. Sometimes air circulating systems serve the three-fold purpose of heating in winter, cooling in summer, and ventilating the year around. When such a system is equipped for automatic control of heat and humidity as well as for purifying the air, it becomes an all-year air-conditioning system.

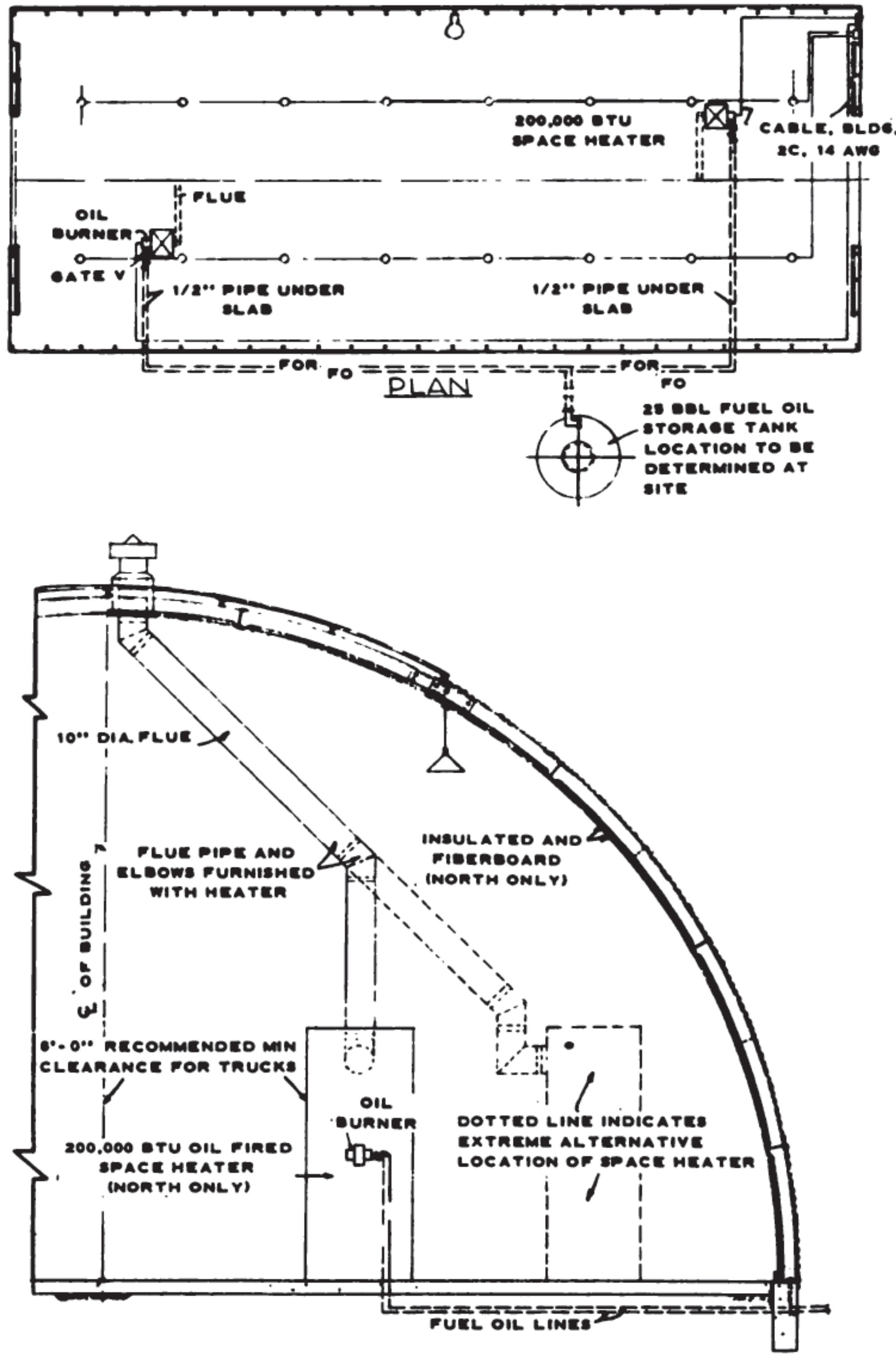


Figure 7–2.—Heater arrangement of 40- by 100-foot arch rib building.

Ordinarily, equipment on large bases is installed by contractors and cared for by civilian employees of the Public Works Department. Your experience with heating and ventilating is more likely to be with the type of equipment used on small advanced bases.

Heating and Air Conditioning of Small Buildings

One of the simplest of Navy heaters is the small 50,000 BTU space heater shown in figure 7–1. These are usually oil-fired. Two of these heaters are standard equipment for a 20- by 48-foot northern quonset hut. A 40- by 100-foot building takes two 200,000 BTU heaters. A typical installation is shown in figure 7–2.

The 200,000 BTU heaters also come equipped with transition pieces for attaching ducts. In this case, the heater can be installed in a lean-to, as shown in figure 7–3. This installation allows for more floor space within the hut and a more even distribution of heat, along with less fire hazard. For heaters of this size or larger, the fuel storage must be located outside the building. In larger advanced base buildings or whenever more heat is needed, more units of this same type and size may be installed.

A paint shop is one place where well designed heating and ventilating equipment is required. Concentrated paint fumes are both poisonous and explosive. Figure 7–4 shows a 20- by 100-foot arch rib building adapted for spray painting. You will note that four heaters are furnished instead of two. This is necessary because of the large amount of air exhausted into the outside atmosphere. No provision is made for recirculating warm air.

Although warm air heaters are used extensively at advanced bases, steam heat is often more convenient for spaces in, and adjacent to, galleys, laundries, or other places where a liberal supply of steam is available. The unit heater, illustrated in figure 7–5, which is suspended from the ceiling, serves very well. It is equipped with an electric-driven

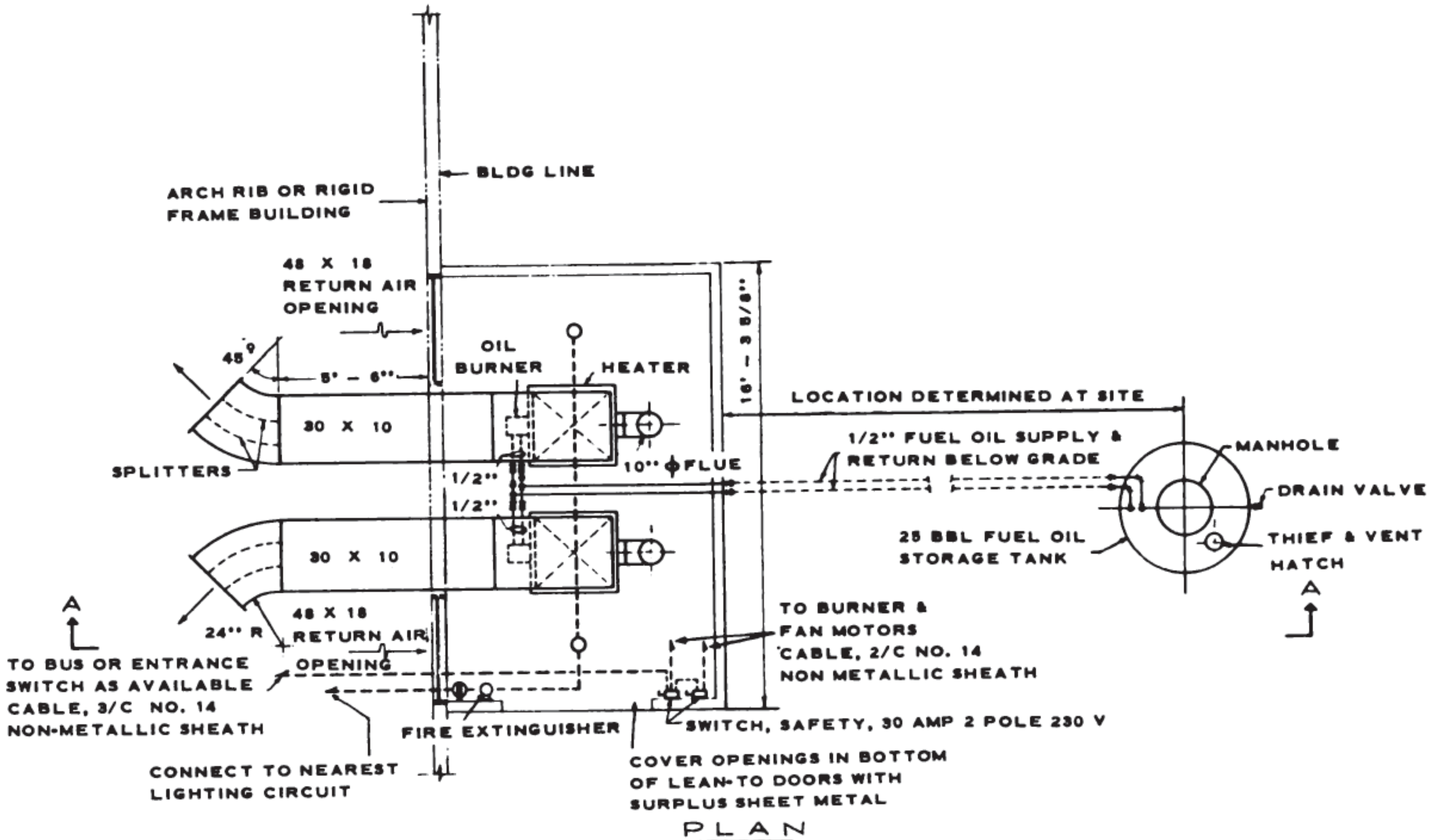


Figure 7–3.—A. Plan of standard hot-air heating system in lean-to.

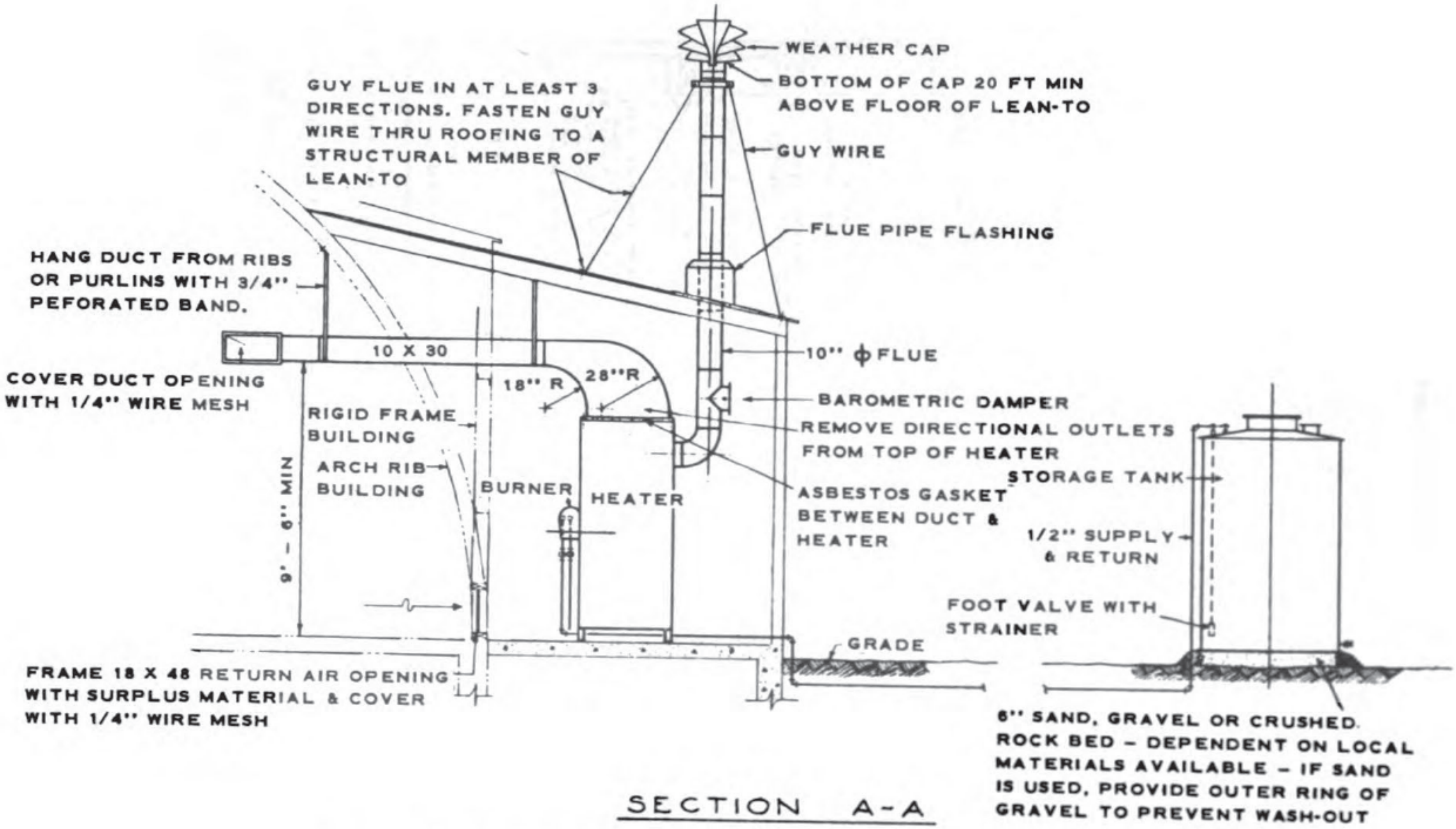


Figure 7–3.—B. Sectional view of standard hot-air system in lean-to.

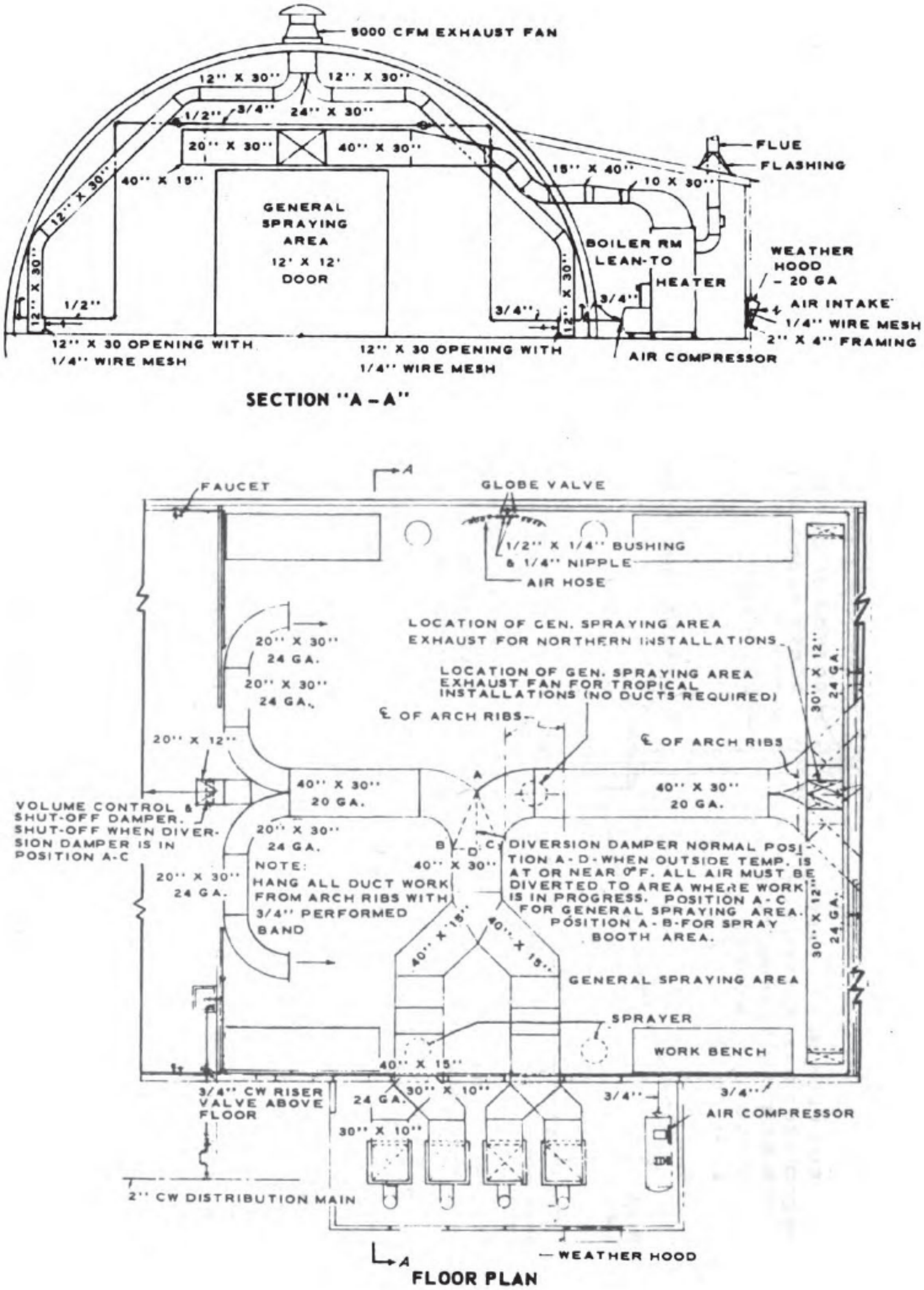


Figure 7–4.—Paint shop.

propellor-type fan and thermostatic control. However, there are some places where any electrical machinery which would produce sparks cannot be used. The mine assembly

building shown in figure 7–6 is one example. The steam radiators used in this building are made up of three sections of copper or finned steel tubing, each 10 feet long. (See fig. 7–7.)

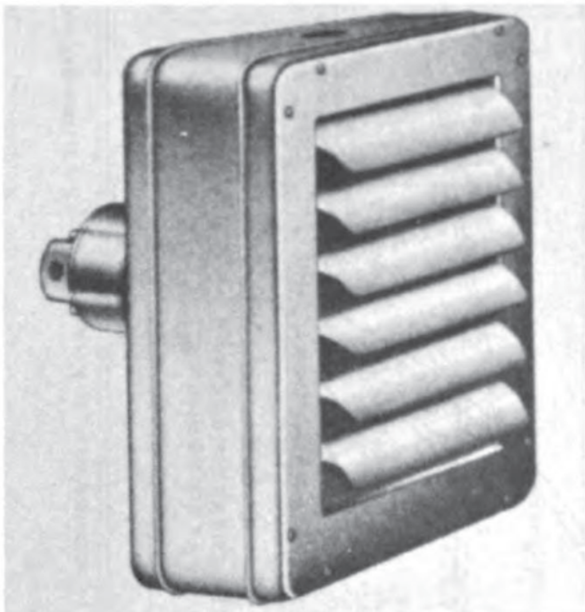
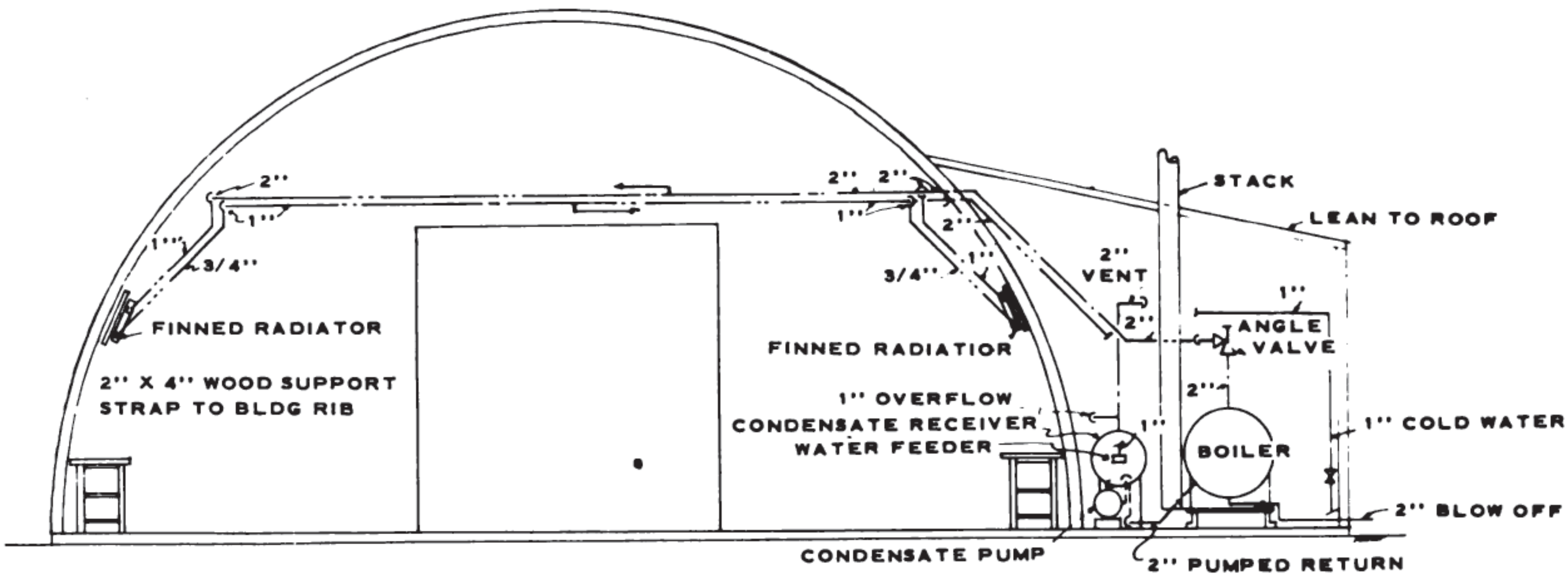


Figure 7–5.—Steam-heated unit heater.

Figure 7–8 shows a 20- by 48-foot hut equipped as a photolithographic printing plant in which strict temperature and humidity control are of prime importance. The air conditioner is a packaged unit similar to that pictured in figure 7–9. These units may be installed with or without ducts. Cooling is accomplished by mechanical refrigeration process. Heat is carried away from the refrigerant condenser by circulating water and is given off to the atmosphere in the cooling tower. For buildings that require greater cooling capacity, more air-conditioning units of this same size may be added.

SHIPBOARD VENTILATION

The greater part of the ventilating fans and duct work in the Navy will be found aboard ship. For this reason, the



SECTION "A-A"

Figure 7–6.—Heating system of a mine assembly building.

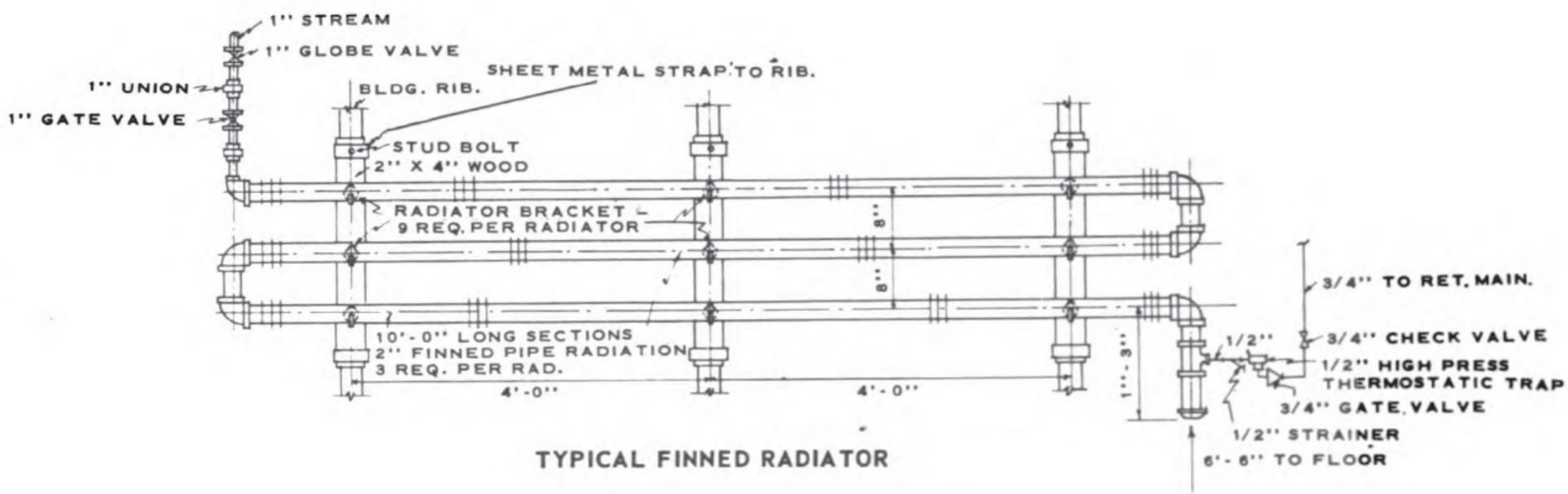


Figure 7–7.—Typical finned radiator.

major portion of this chapter is devoted to a description of shipboard ventilation. The main difference between the ventilation systems of ships and those of buildings is the watertight and airtight construction of the ducts on a ship. Also,

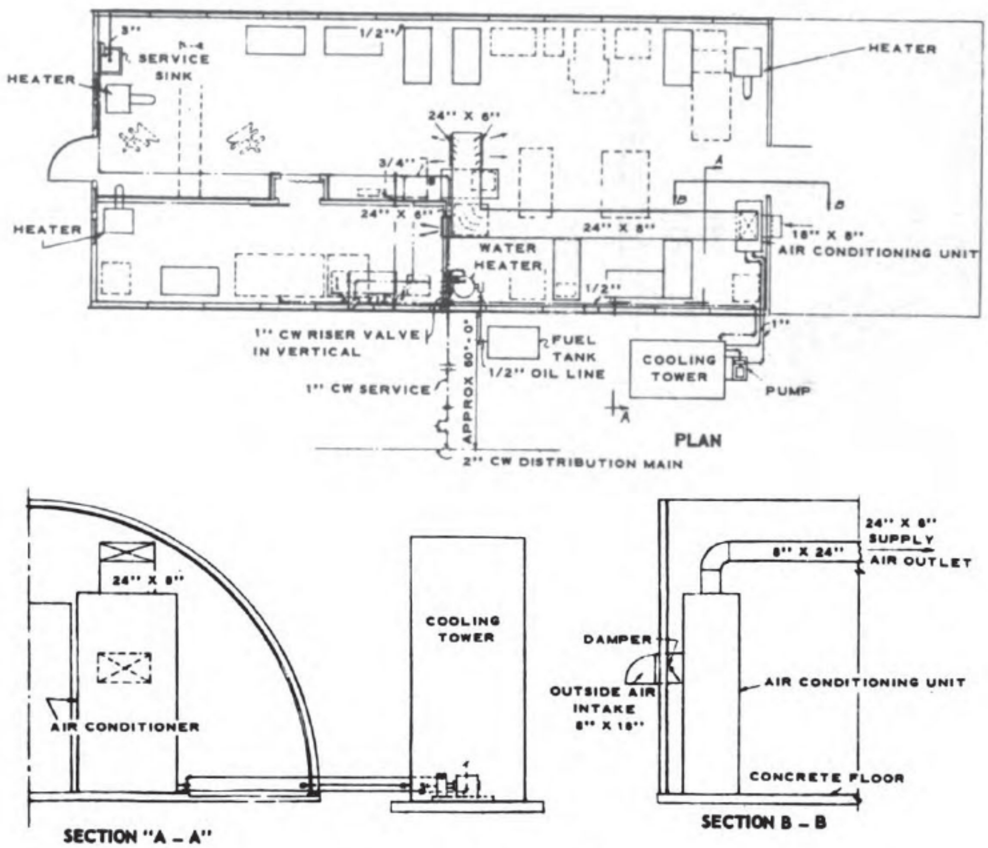
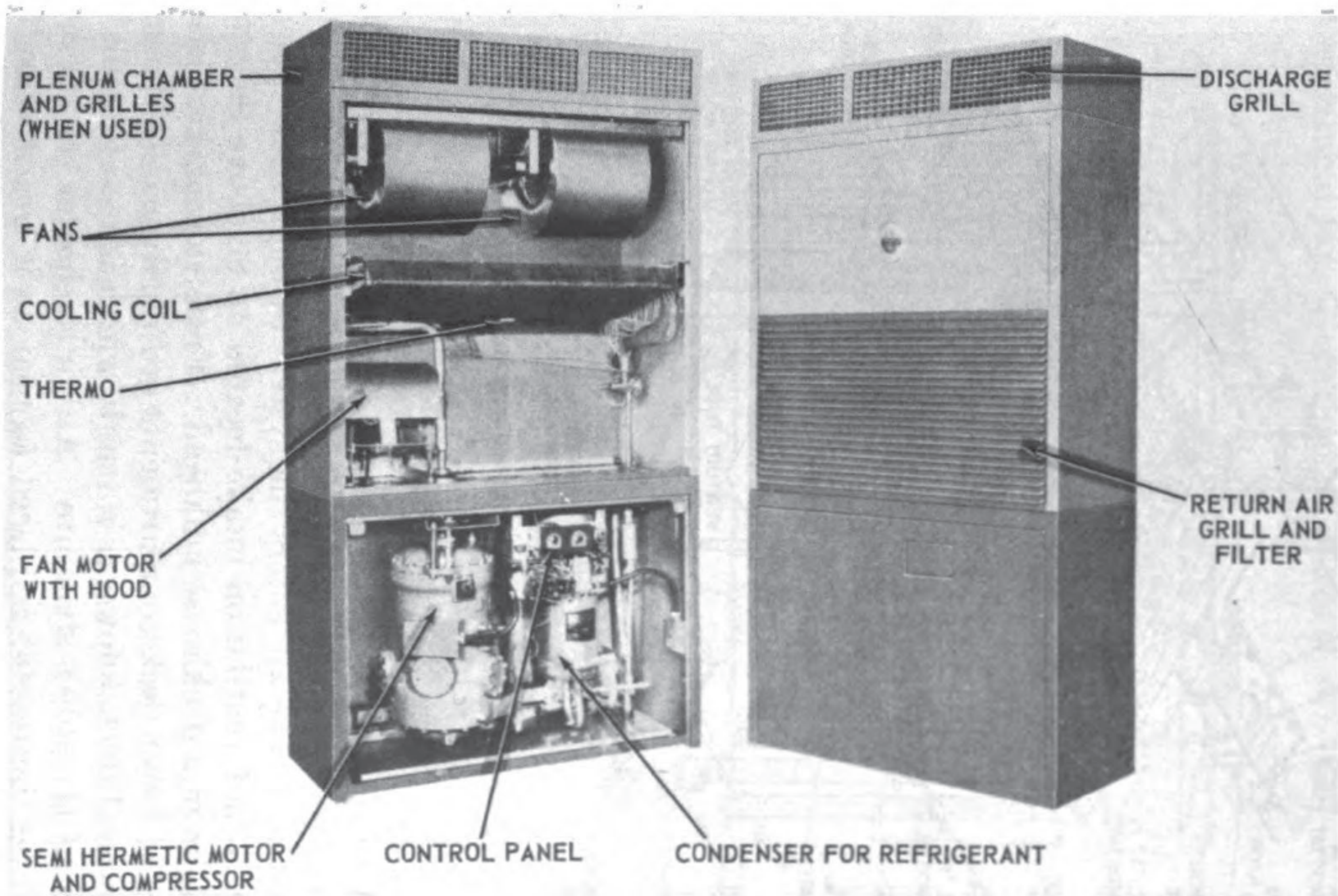


Figure 7–8.—Photo-litho printing plant.

shipboard equipment will, in many cases, be of sturdier and more costly construction, since its proper functioning and reliability are of vital importance.

To preserve the watertight integrity of a vessel, shipboard ventilation is divided into many small systems. Some of these systems are for supply and others for exhaust. Figure 7–10 shows the general characteristics of one supply system and one exhaust system.



Courtesy Chrysler Airtemps Division, Chrysler Corporation

Figure 7–9.—Air conditioner.

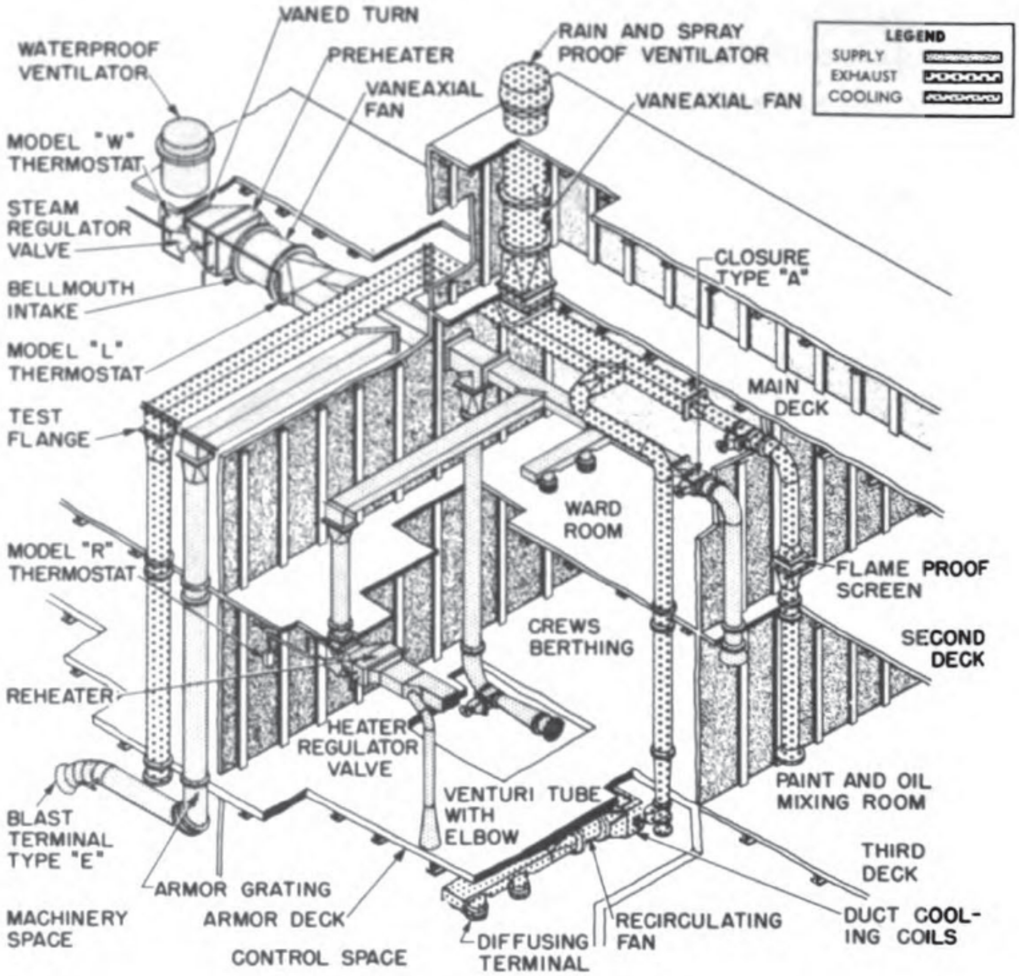


Figure 7–10.—Shipboard ventilation systems.

Supply Systems

A supply ventilation system is designed to serve a group of compartments and spaces with an adequate amount of fresh air. The air enters the system through some type of waterproof ventilation intake located on or above the main deck or in a deckhouse bulkhead. From the intake, the air for the lower deck compartments ordinarily passes through a vertical duct, known as a trunk, which is usually built as part of the ship's structure. An air preheater with a controlling thermostat is placed as near as is practical to the intake end of the system.

A fan provides the suction to pull the air into the intake and down the trunk. The fan may be of either the centrif-

ugal type or the axial flow type. An axial flow fan has important advantages in that it takes less space, saves weight, cuts down noise, and offers less resistance to the air flow than a centrifugal fan. Note the differences shown in figure 7–11.

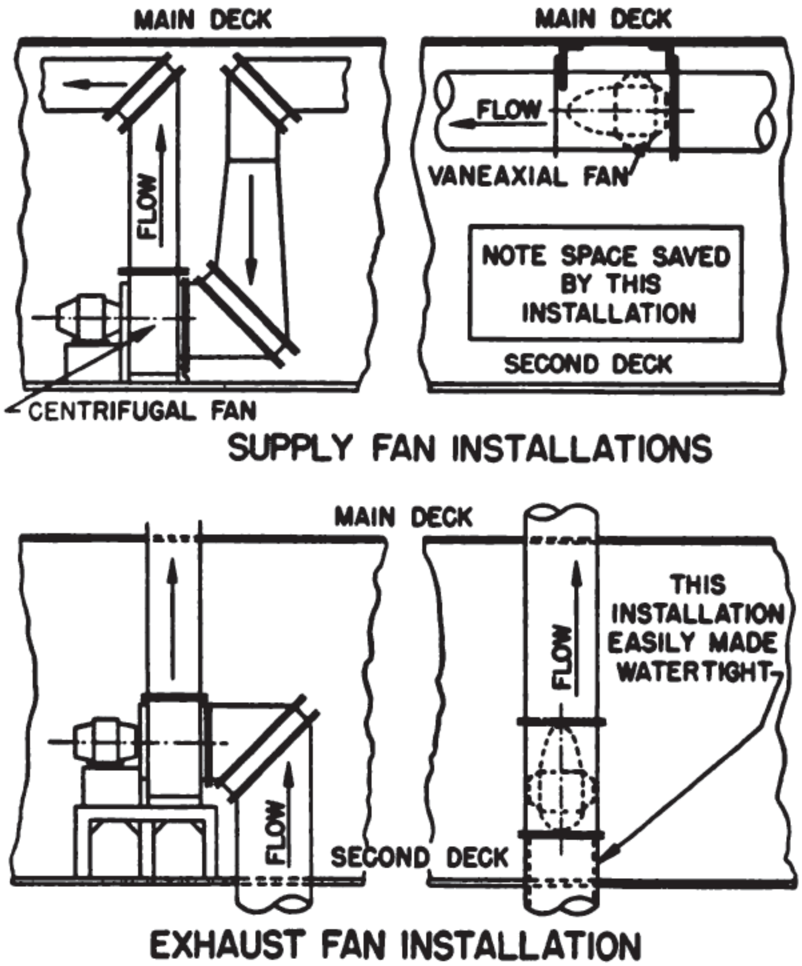


Figure 7–11.—Fan installations.

In an intake system serving a large number of compartments, the air leaving the fan goes first through a main, then through branch mains, and finally through smaller branches. The sizes of the supply system ducts are based on the number of cubic feet of air to be delivered to the various compartments and spaces per minute. Reheaters are located in the branch mains or smaller branches to serve a group of individual spaces or compartments. At the end of the line, air

is delivered through end openings known as supply terminals. In some types of terminals, dampers are installed which can be manually operated to control the amount of air ejected through the terminals. The supply output is checked with various types of velocity meters and pressure gages. Because each system is scientifically designed and balanced, branches cannot be added without a study of the whole system. When any alterations are contemplated, all possible effects on the whole system should be considered.

Exhaust Systems

Ordinarily one exhaust system serves the same spaces and compartments that are served by one supply system. Axial flow fans are never used in exhaust systems if the air might contain flammable or explosive vapors or fumes. Instead, centrifugal fans must be used to exhaust such vapors. Also, exhaust branches serving compartments where flammable liquids are stored must be provided with flame arresters. (See fig. 7–12.) Naturally, preheaters and reheaters are not placed in exhaust lines.

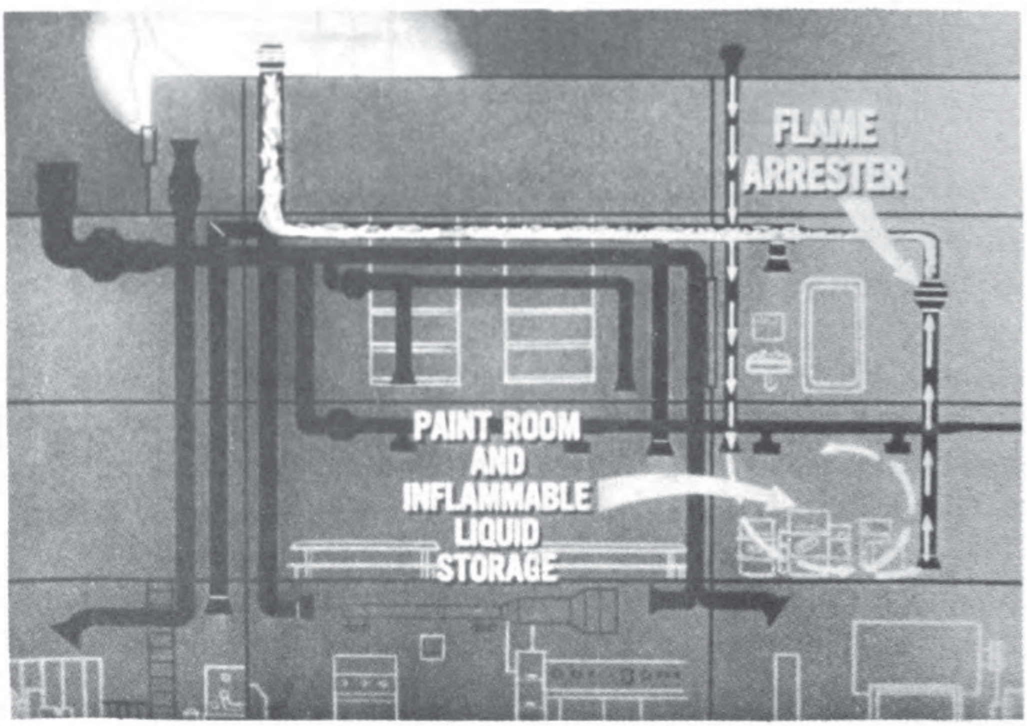


Figure 7–12.—Flame arrester in exhaust duct.

Duct Design

In designing ventilation ducts, the designer must constantly keep in mind that the watertight integrity of compartments and spaces served by the ventilation system must be maintained. Watertight integrity is particularly important for branches which extend to lower decks and platforms. Penetration of watertight and armored decks and bulkheads is avoided whenever possible. When ducts must pass through such boundaries, they must be watertight with specified closures and fittings of welded construction.

In order for air to move through ducts efficiently with minimum friction loss from seams, joints, turns, and fittings, the interior of ducts must be streamlined. Also, in order that excessive noise be avoided, seams, splitters, dampers, vanes, and terminals should be carefully designed so that air can flow quietly over and around them. When flowing air hits a sharp edge, the effect is similar to that produced when someone blows on the reed of a harmonica or clarinet.

Headroom and space limitations must also be considered. Round ducts offer the least resistance to moving air so that they are used whenever space permits. Rectangular sections are used whenever space limitations prohibit the use of round sections. It is not permissible to run ducts through square or rectangular openings in decks, bulkheads, beams, or girders. Such holes must be round, oval, or flat-oval in shape to minimize the decrease in structural strength.

Duct sections are ordinarily made of galvanized steel, unless some other material, such as aluminum or corrosion-resisting steel, is specified. All ducts which pass through compartments subject to pressure tests must be strong enough to withstand the testing pressure.

Supply ducts should never have terminals which discharge air toward electrical installations. The salty moisture in the air will cause such equipment to deteriorate rapidly.

Seam Allowances

Welded seams are preferred for watertight ducts. Round ducts made of heavy metal are sometimes lapped at the seams and riveted with tinner's rivets. The lapped surfaces are tinned before riveting and then sweated together after riveting. Total lap allowance is usually from ¾ inch to 1 inch.

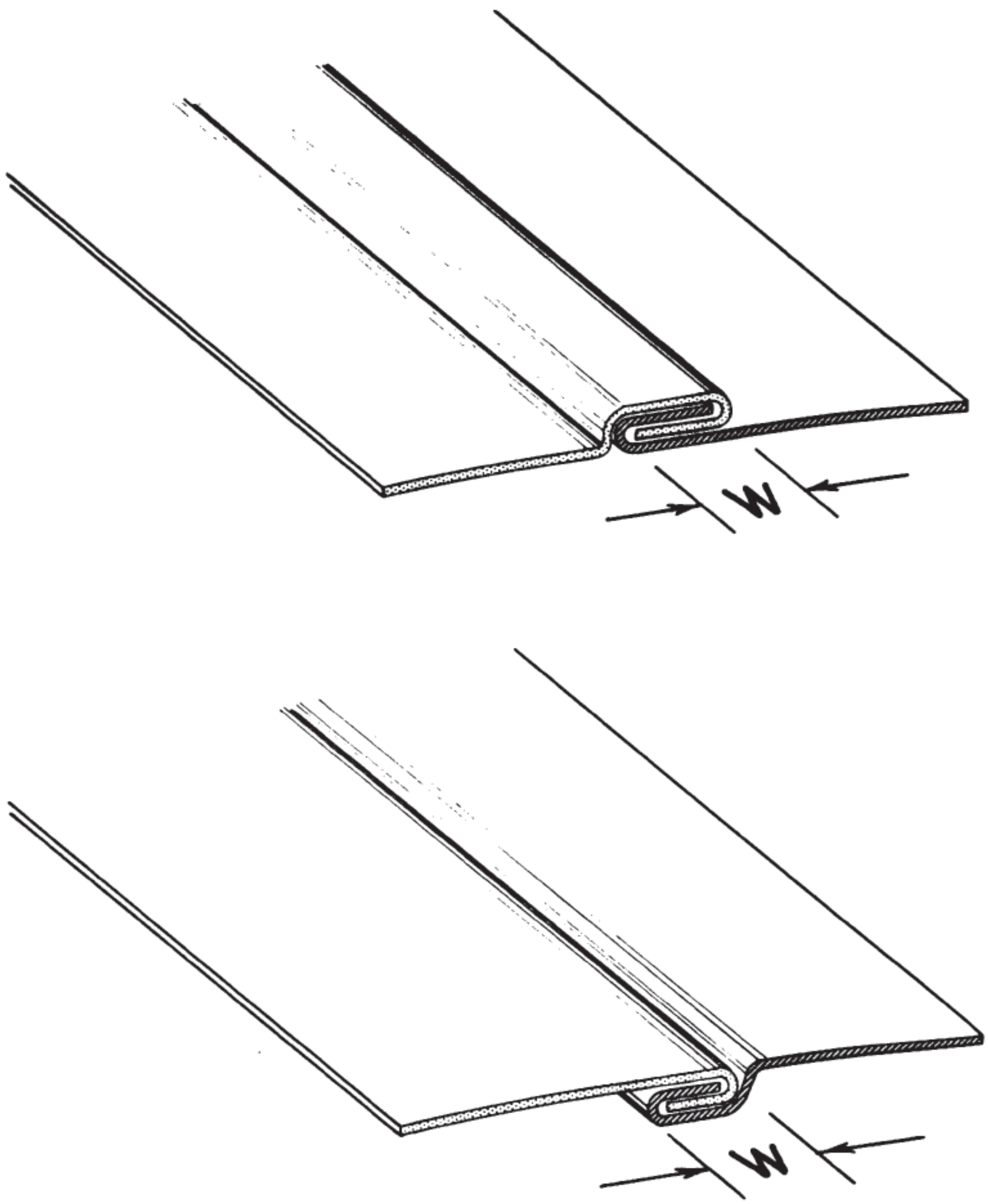


Figure 7–13.—Grooved seams.

Round sections made of thin metal may be assembled with grooved seams. (See fig. 7–13.) Rectangular ducts may be riveted or assembled with double seams. The four steps in forming a double seam are shown in figure 7–14.

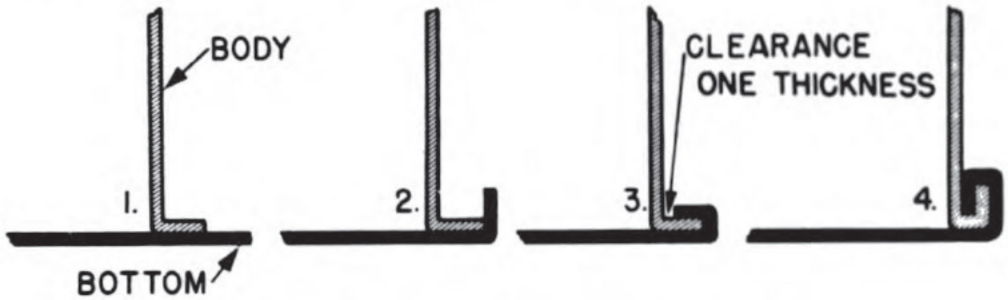


Figure 7–14.—Forming a double seam.

Stiffeners for Rectangular Ducts

Stiffeners are used to minimize vibration of the walls of large rectangular ducts. They are usually made of lightweight angle bars and riveted to the outside of the ducts, as shown in figure 7–15. No stiffeners of any kind are to be placed inside a duct.

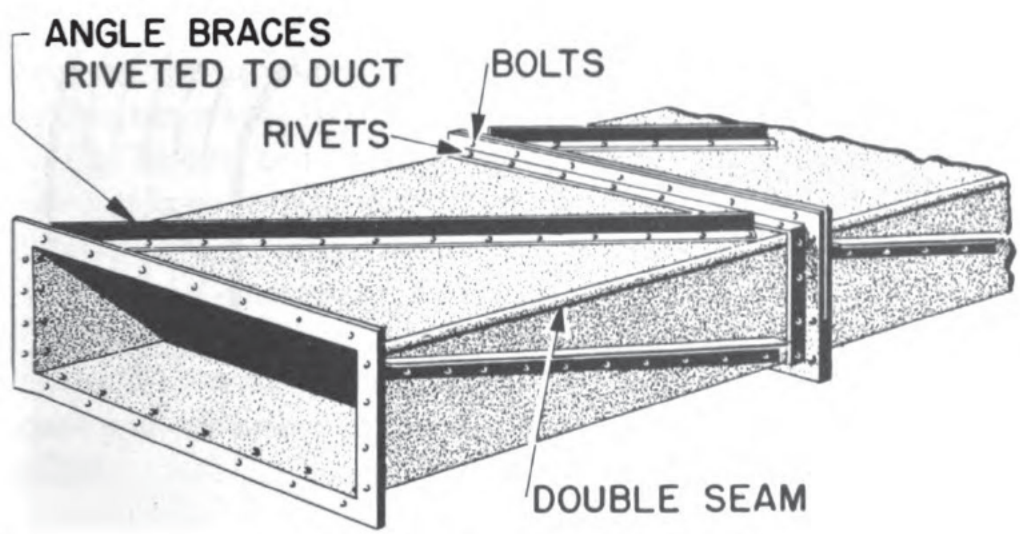


Figure 7–15.—Installation of large rectangular duct stiffeners.

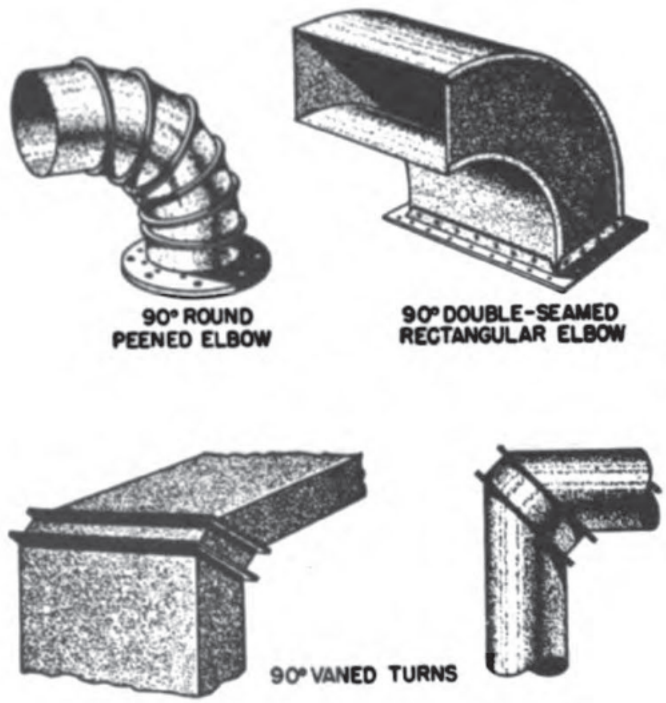


Figure 7–16.—Elbows and vaned turns.

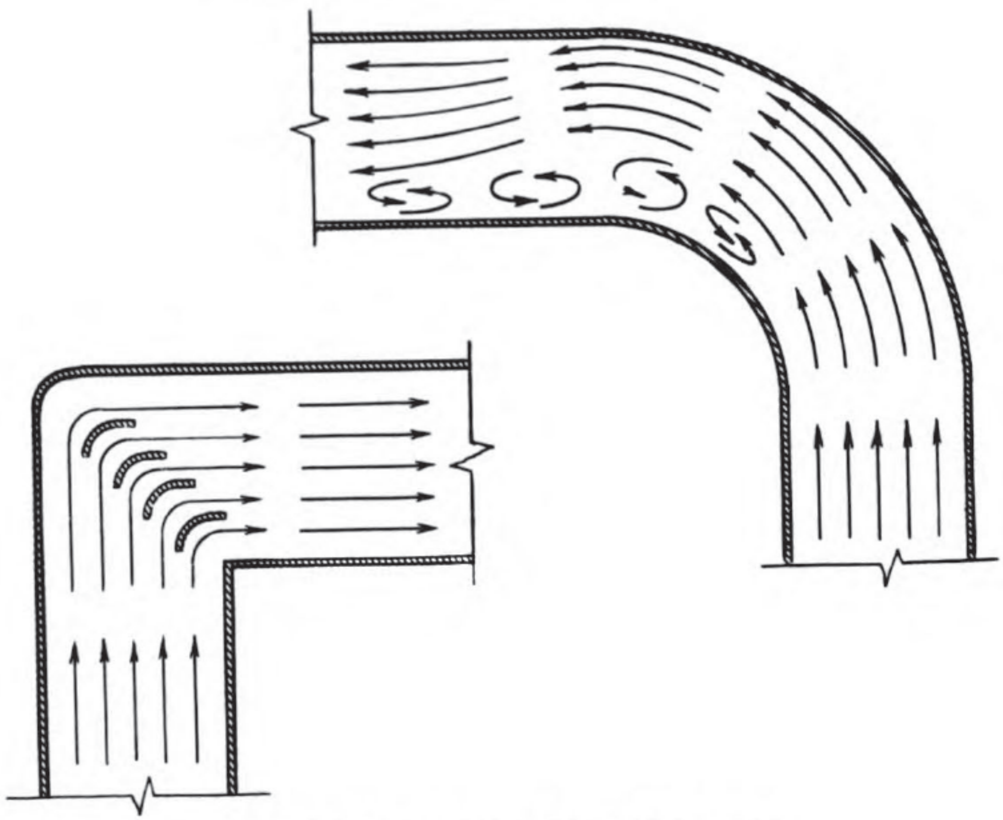


Figure 7–17.—Action of air currents in turns.

Turns

Turns in air ducts should be as few and as far between as it is practicable to make them. Formerly most turns were of the elbow type, also called radius turns, for both round and rectangular ducts. Now the trend is toward vaned

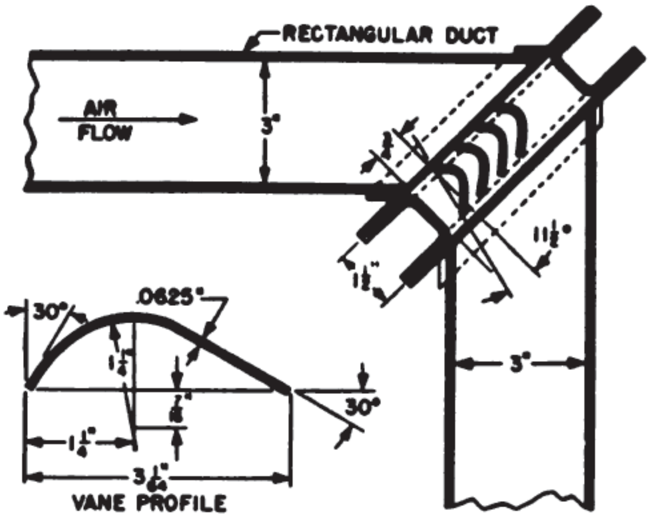


Figure 7–18.—Design of a vaned rectangular turn of 90 degrees.

turns. (See fig. 7–16.) Figure 7–17 shows the action of moving air in the two types of turns. The turbulence created in an elbow turn of short radius produces considerable resistance to the flow of air.

The design and construction of vaned turns for shipboard use has been standardized by BuShips. These turns may be requisitioned ready made for repair or replacement work. Only in an emergency will one have to be made. Information necessary for making 3-inch grids for 90-degree vaned turns to fit rectangular ducts is given in figure 7–18 for use in case you are asked to lay one out. The vanes are welded in place.

Tees and Takeoffs

Ordinarily when a branch takes off from a main, the size of the main is reduced where it extends past the TAKEOFF.

The REDUCER connecting the two sections is the proper place to locate the takeoff. A concentric reducer, with a takeoff, is illustrated in figure 7–19. It is used with either supply or exhaust systems.

Rectangular TEES which connect two branch mains to the end of a main duct are constructed as shown in figure 7–20.

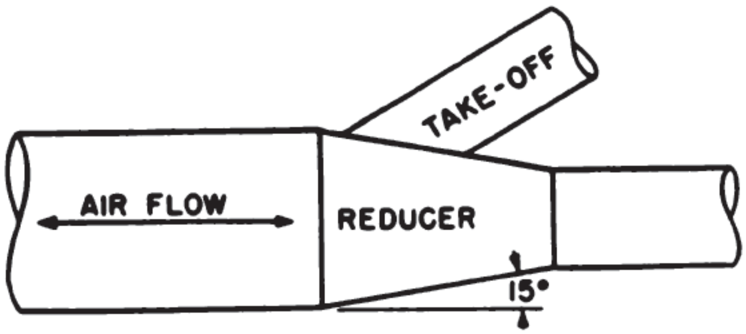


Figure 7–19.—Concentric reducer with takeoff.

With appropriate vaned turns, the branch main can be taken off at various angles. The branch main shown in figure 7–21 is taken off at an angle of 90 degrees. Notice the SPLITTER. It proportions the amount of air directed into the branch main. The splitter is usually made so that it is adjustable, but after its correct location is determined, it is riveted in place.

Small round branches are sometimes taken off branch mains, as illustrated in figure 7–22. Notice the SCOOP, which can be used to feed air into the branch. Figure 7–23 shows how the leading edges should be streamlined.

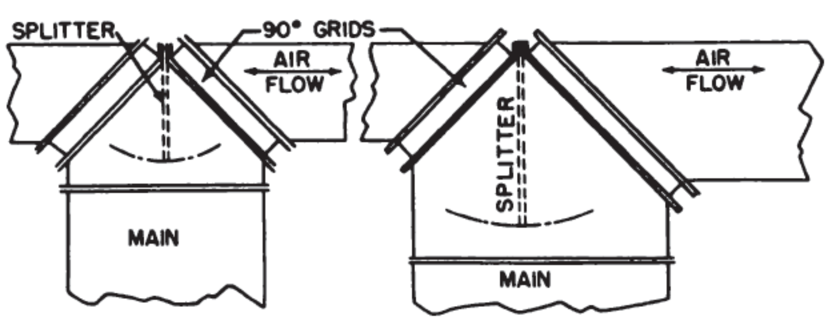


Figure 7–20.—Rectangular tees.

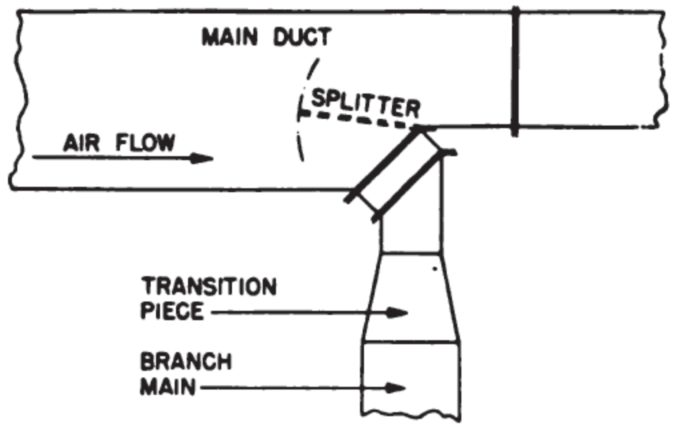


Figure 7–21.—Takeoff from rectangular duct.

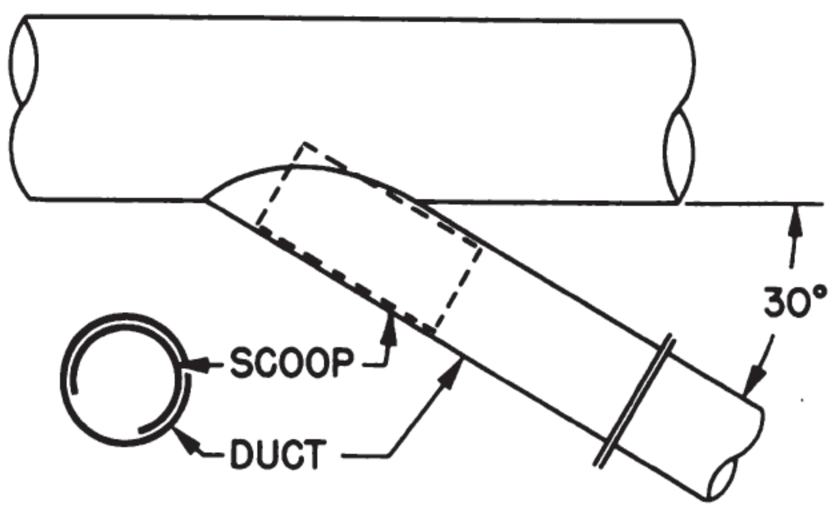


Figure 7–22.—Thirty-degree branch takeoff with scoop.

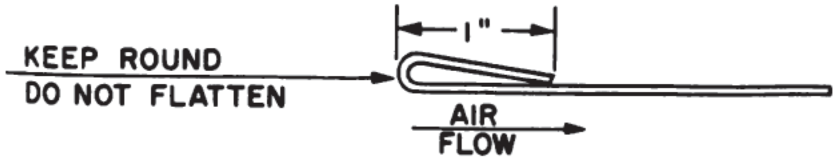


Figure 7–23.—Streamlining of edges.

Venturi Tubes and Armor Gratings

Ducts passing through armored decks require special installations. Watertight ducts which are 8 inches or less in diameter pass through round holes and are welded to the

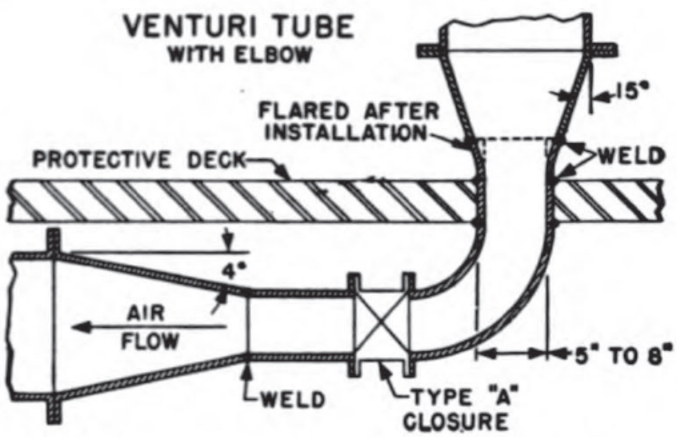


Figure 7–24.—Venturi tube in armored deck.

deck. A duct more than 8 inches in diameter is connected to a venturi tube, provided the hole for the tube does not exceed 8 inches in diameter or that the velocity of the air will not

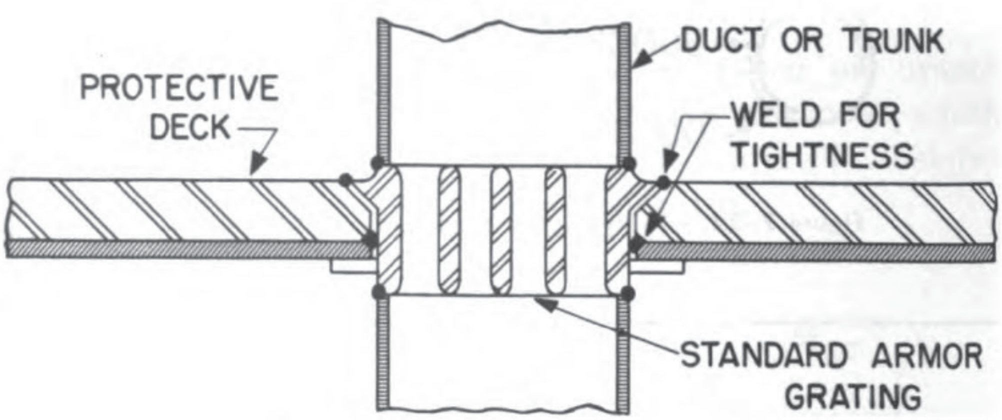


Figure 7–25.—Use of armored gratings.

exceed 10,000 feet per minute. Figure 7–24 illustrates an elbow-type venturi tube. Larger ducts require the use of armor gratings, which are installed as shown in figure 7–25.

Types of Terminals

Living-space supply terminals are ordinarily installed in a vertical position. The open end of the terminal is usually located between 9 and 18 inches from the deck in berthing spaces and below the lowest bunk. The cone-shaped outlet is designed to lessen the velocity of the air that is discharged into the space.

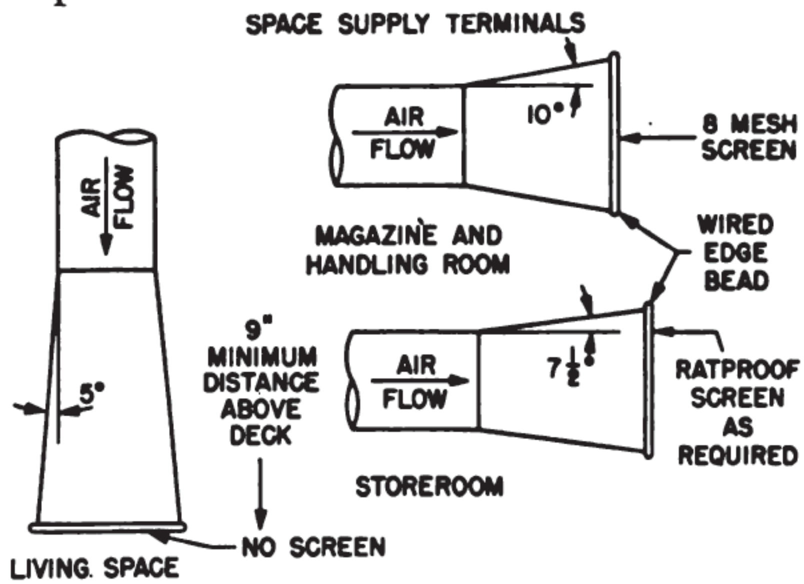


Figure 7–26.—Standard space supply terminals.

Supply terminals for magazines, handling rooms, and staterooms are located in a horizontal position near the overhead. The design of various terminals is shown in figure 7–26.

Adjustable supply terminals are used in hot spaces, such as engine and machinery rooms, radio and sound rooms, workshops, laundries, and turrets. Adjustable slip sections

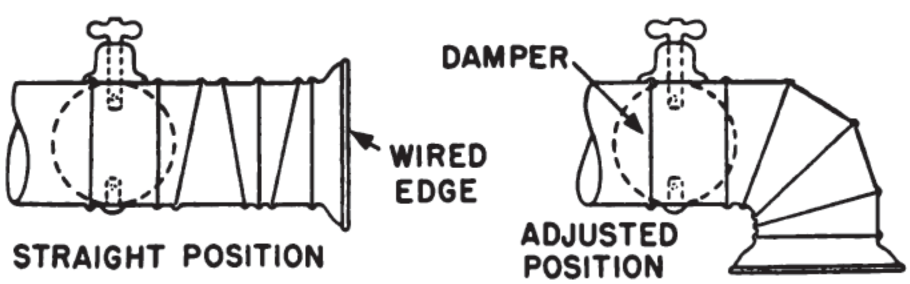


Figure 7–27.—Adjustable supply terminal.

provide a means of controlling air direction. (See fig. 7–27.) Air can thus be discharged directly in the vicinity of most of the personnel.

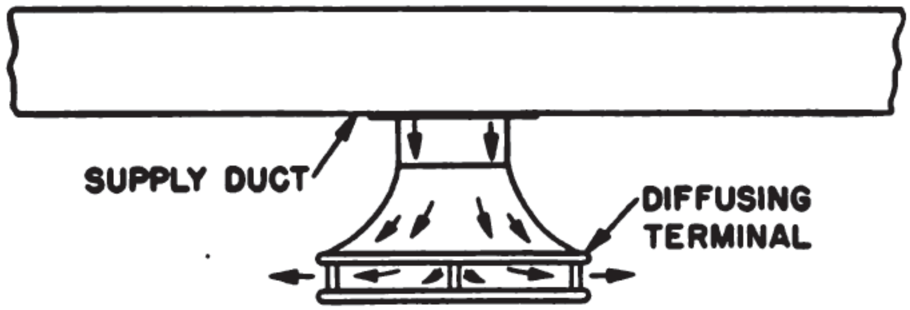


Figure 7–28.—Diffusing terminal.

Navy standard diffusing terminals are used in offices, staterooms, wardrooms, mess rooms, and in spaces which have air conditioning. A standard diffusing terminal is installed in a duct as shown in figure 7–28. Figure 7–29 shows a bell-mouth exhaust terminal.

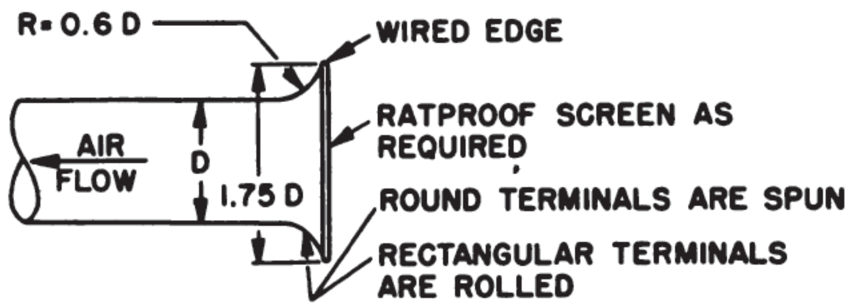


Figure 7–29.—Exhaust terminal.

Access Plates

Access plates are placed in ducts to provide an easy means of inspection and to facilitate assembly and cleaning. An access plate is ordinarily round and is closed with a cover plate. A collar is fitted to the opening in the duct and flush riveted into place. The cover plate is sealed with a suitable gasket and secured to the collar with QUICK FASTENERS that fit into holes in the collar.

Insulation of Ventilation Ducts

Ducts are covered with insulating material whenever it is necessary to prevent condensation or objectionable gain or loss of heat. Such is the case when a supply duct passes through a heat-producing space, or when any duct passes through a refrigerated space. Ventilation heaters are insulated to keep in the heat and to protect personnel from burns.

Duct Hangers and Brackets

Ventilation duct sections and fittings are supported by hangers, brackets, and braces. These are designed to hold the ventilation lines securely in place and to minimize vibration. Supports for lines should be placed so that fittings and sections of ducts may be easily disconnected for maintenance, repair, and replacement.

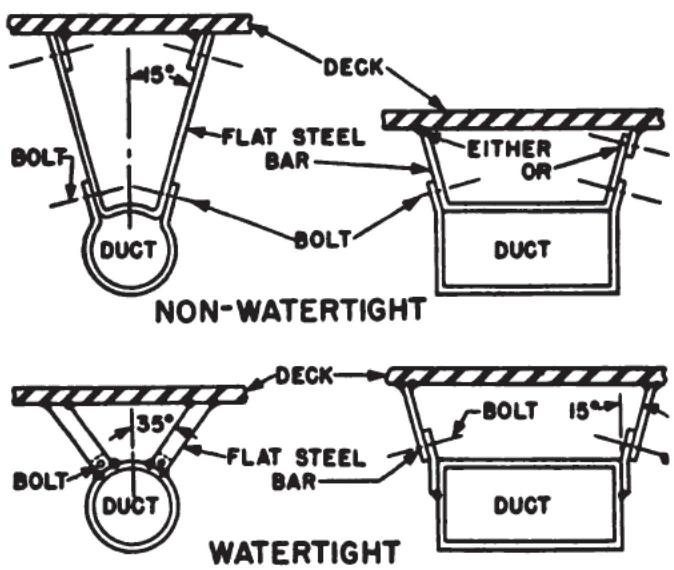


Figure 7–30.—Duct hangers and brackets.

A typical assortment of hangers and brackets is shown in figure 7–30. These are made of flat steel bar stock. Some ducts and terminals may require heavier supports made of angle stock.

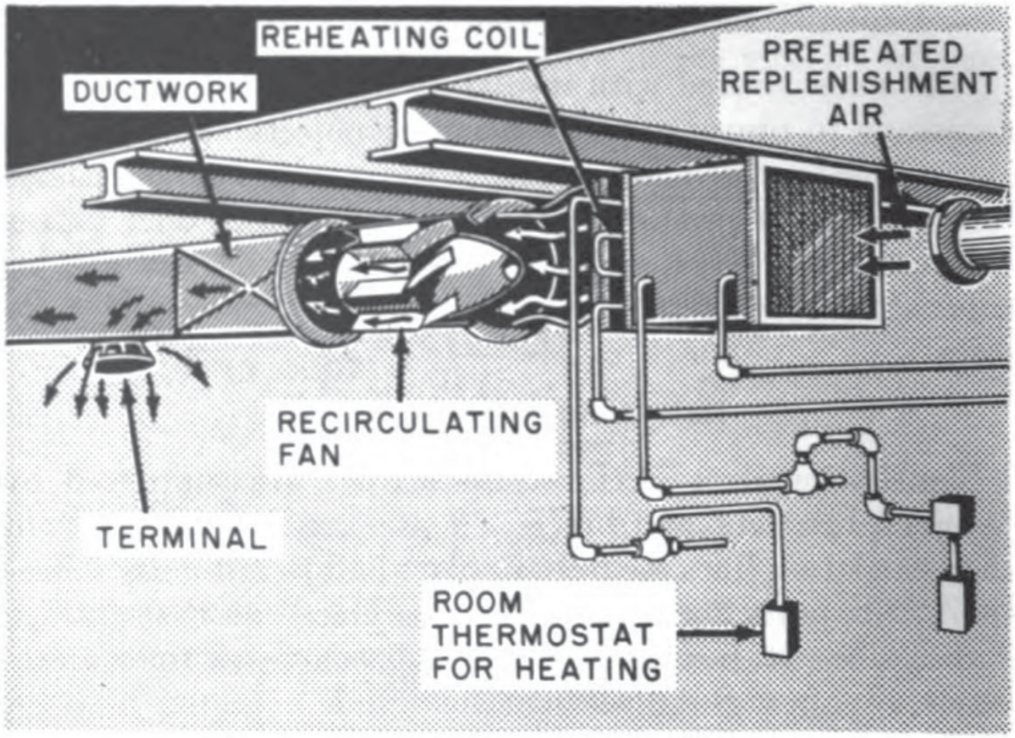


Figure 7–31.—Heating equipment of recirculating system.

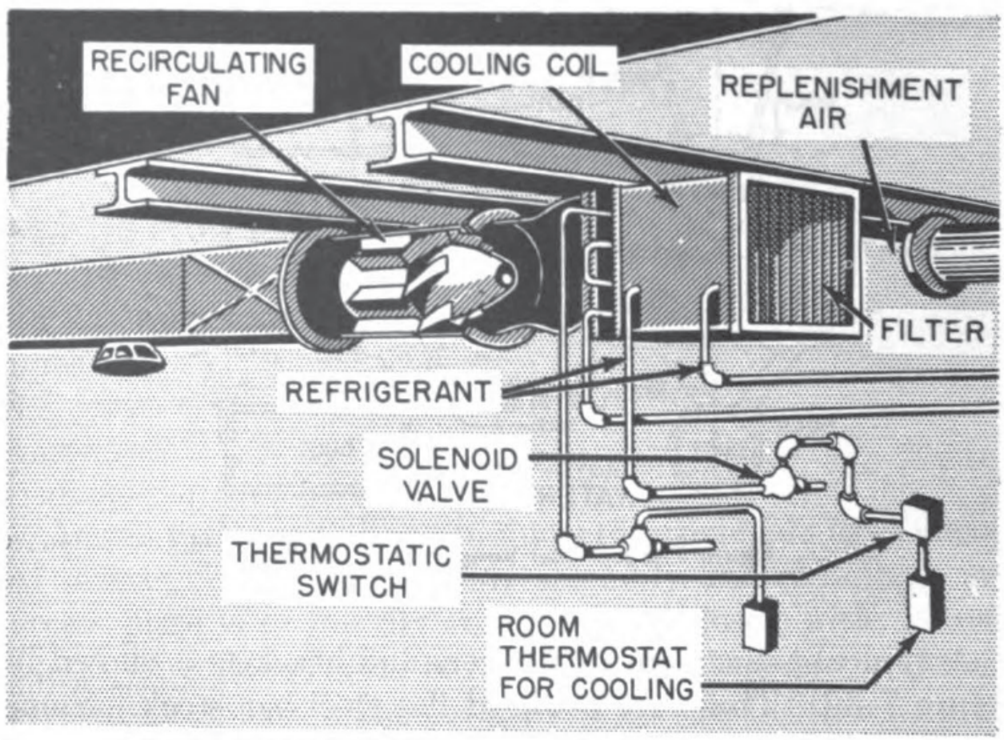


Figure 7–32.—Cooling equipment of recirculating system.

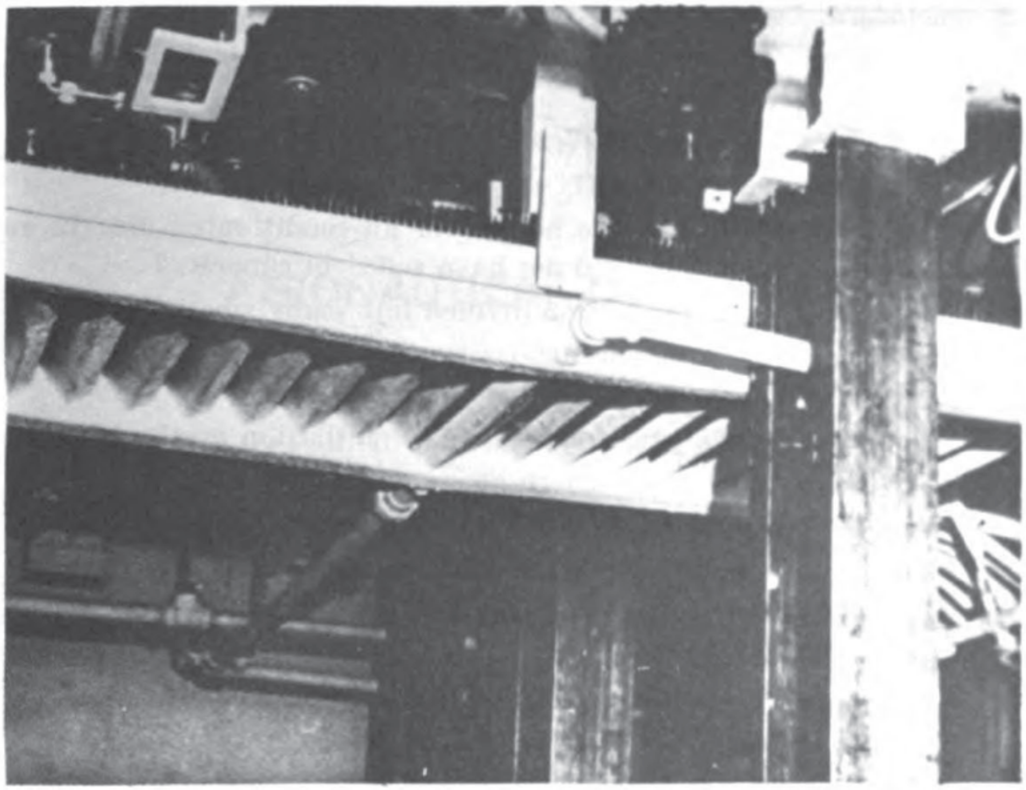


Figure 7–33.—Air cooling coil, gravity circulation.

Mechanical Cooling

Mechanical cooling is provided in submarines and very often in certain spaces on surface ships where it is of importance for the comfort, health, and alertness of personnel or for the preservation of equipment. Figures 7–31 and 7–32 show the interior arrangement of the parts of an air recirculating system which is provided with both a heating coil and a cooling coil, each controlled by a thermostat. A gravity cooling coil is illustrated in figure 7–33. This method of air cooling is required in magazines and in spaces where flammable vapors make the use of electric machinery unsafe.

QUIZ

1. Give two reasons for regulating atmospheric conditions within certain enclosures.
2. What is meant by 50 percent relative humidity?

3. Name five things that affect the heat gain or loss within an enclosure.
4. Name three types of heating systems used in large buildings.
5. Name two types of heating equipment used at advanced bases.
6. Why is it not permissible to use electrical machinery or oil-fired heaters in some buildings?
7. What could be done if the heating or air-conditioning unit in an advanced base building did not have sufficient capacity?
8. Why is shipboard ventilation divided into many small systems?
9. Name one important characteristic that a shipboard ventilation intake should have.
10. Where is the preheater installed in a ventilation system?
11. What two types of fans are in general use aboard ship?
12. Name one place where an axial flow fan cannot be used.
13. Where is a reheater usually installed in a supply system?
14. What largely determines the size of supply ducts?
15. What is likely to happen if a new branch is added to an existing ventilation line without a careful study of the whole system?
16. Give two reasons why duct interiors should be streamlined.
17. Name four kinds of seams used in duct work.
18. What important advantages do vaned turns have over the older radius turns?
19. What is the purpose of a splitter?
20. When are venturi tubes and armor gratings used?
21. Why are living-space supply terminals cone-shaped?
22. What type of supply terminal would very likely be used in a heat generating space that could not be cooled throughout?
23. When is insulating covering for ducts used?
24. Where are gravity cooling coils usually used?

CHAPTER 8

AERONAUTICAL DRAFTING

INTRODUCTION

Regardless of your present duty assignment, you will probably be required to do some aircraft drawing sooner or later. Although aircraft drawing follows, in general, the procedures of other mechanical drawing, it presents some problems rarely encountered elsewhere. Airplane drawings made by the Navy consist principally of drawings of rework, repair, and modifications to be made by the service activities for existing aircraft. To be a good aircraft draftsman, one needs to learn the structural methods and principles applied to modern aircraft. This is made no easier by the fact that in aviation, design and structural methods are constantly changing.

An understanding of geometry is important, as well as skill in both orthographic and pictorial drawing and in development as applied to sheet metal work. It is often more convenient to determine measurements graphically, rather than mathematically. This requires precise measurements of the known distances and angles, care in transferring the measurements, and ability to draw smooth lines which meet accurately at points of intersection.

CONVENTIONS AND STANDARDS

Besides the military drawing standards set forth in JAN–STD–1, *General Drawing Practice*, MIL–STD–8, *Dimensioning and Tolerancing*, and the other publications in this series, there are usually additional standards set up by individual activities to meet their needs. When drawings are to be made

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for a particular airplane, the drawing practices followed by the manufacturer of that plane will also serve as a guide.

Scale and Format

As a general rule, detail and assembly drawings are made actual size. This necessitates the use of drawing sheets of greater width and sometimes of great length. It is desirable however, that the length should not exceed 144 inches. On large-sized drawings, horizontal and vertical zoning may be used as an aid to the location of items when the drawing is read. The approved method of zoning is described in JAN–STD–3, *Format for Production Drawings.*

Large detail, assembly, and installation drawings may be drawn to a reduced scale if information can be clearly shown in all respects. In order to do this, section or partial views may be drawn actual size where necessary. Draftsmen should bear in mind that the purpose of reducing the scale of a drawing is to reduce the size of the sheet to be handled and to avoid wastage of drawing and blueprint paper and file space. Therefore, as small a sheet should be used as practicable without crowding the drawing. Enough space should be left so that sectional views, notes, or tabulations can be added if these become necessary during the life of the drawing.

It is customary for every airplane part to have a number which corresponds with its detail drawing number. If more than one part is shown on one detail drawing, further identification may be accomplished by DASH NUMBERS. Thus, two parts shown on a single drawing may be numbered 34105–1 and 34105–2. On the drawing, the dash number preceeded by the dash should be placed in a small circle near the part it identifies. An arrow drawn from the circle should touch the outline of the part.

Sometimes, dash numbers are also used to distinguish between right-hand and left-hand parts which are mirror images of each other. In this case, the left-hand part may be shown and the right-hand part indicated by a note.

Drawing titles are given with identification first and description second. For example, the title FLANGE—CARBURETOR AIR INTAKE would be read, "carburetor air intake flange."

Views and Projections

Draw only as many views in third-angle orthographic projection as are needed to clearly illustrate the part to be made. It is customary for principal views to be taken from the left side of the airplane with the nose pointed toward the left border of the drawing sheet. Partial views and sections may be used to illustrate certain features, thus making a greater number of complete views unnecessary.

One view may be used, for example, in drawing in a stud if the diameters are clearly marked as diameters. One view of a detail should correspond to the position of the view as shown on its next assembly drawing whenever possible. However, a part which is shown in an angular position when it is assembled should not be drawn in an angular position as a detail.

Sections should be projected directly if space permits, but if it is limited, a section view may be placed elsewhere on the sheet or on a separate sheet. Views which are not projected directly should be clearly marked to indicate the location from which they were taken and the direction in which they are viewed.

Various systems of station marking are used on aircraft drawings. For example, the center line of the airplane on one drawing may be taken as the zero station, and objects to the right or left of center along the wings or stabilizers may then be located by giving the number of inches between them and the center line zero station. On other drawings, the zero station may be at the nose of the fuselage, at a firewall, at the leading edge of a wing, or at some other location, depending on the purpose of the drawing and the custom concerning the particular part or assembly. (See fig. 8–1.)

Isometric, perspective, or photographic views may be employed under some conditions where one of these types of

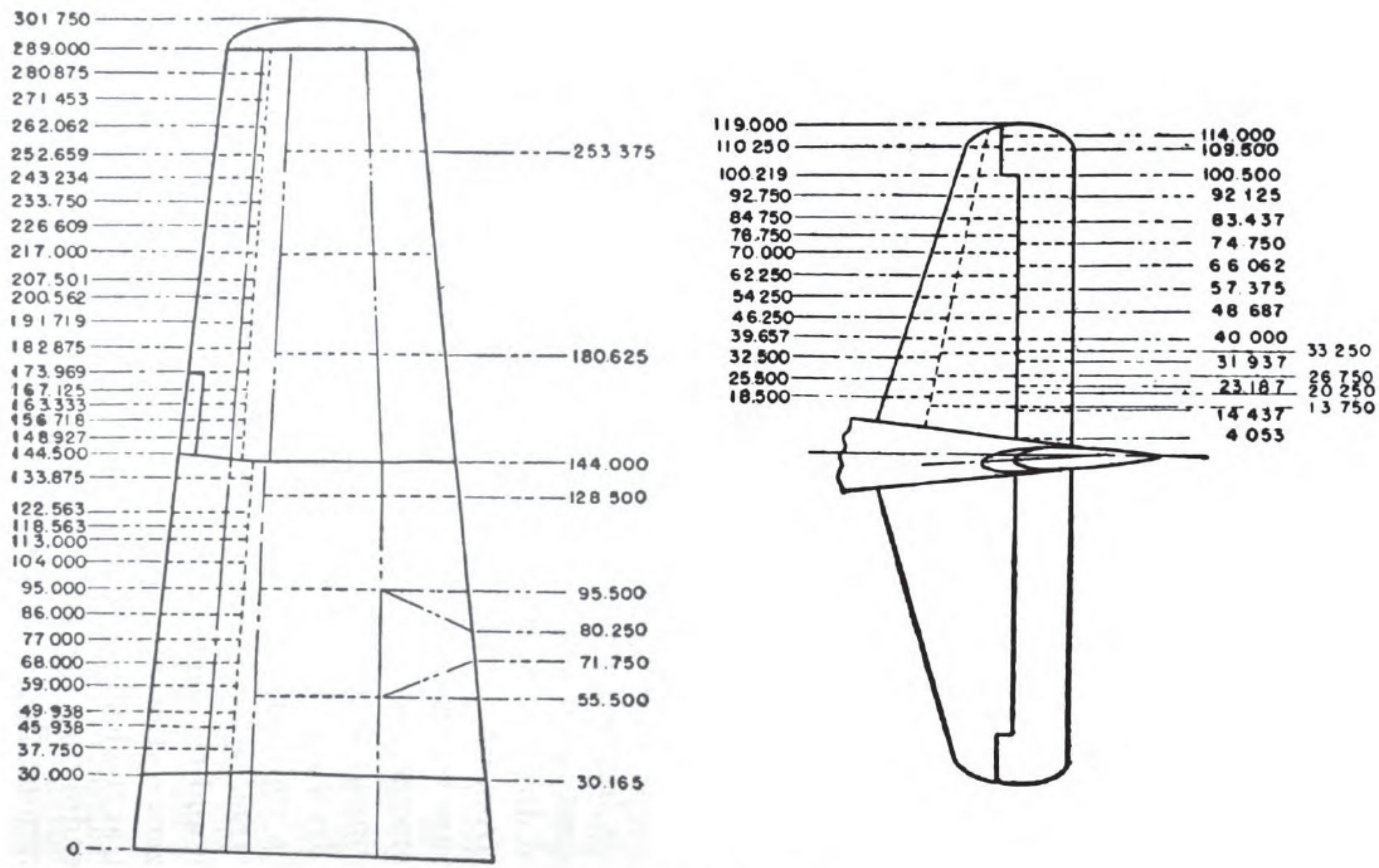


Figure 8–1.—Station marking.

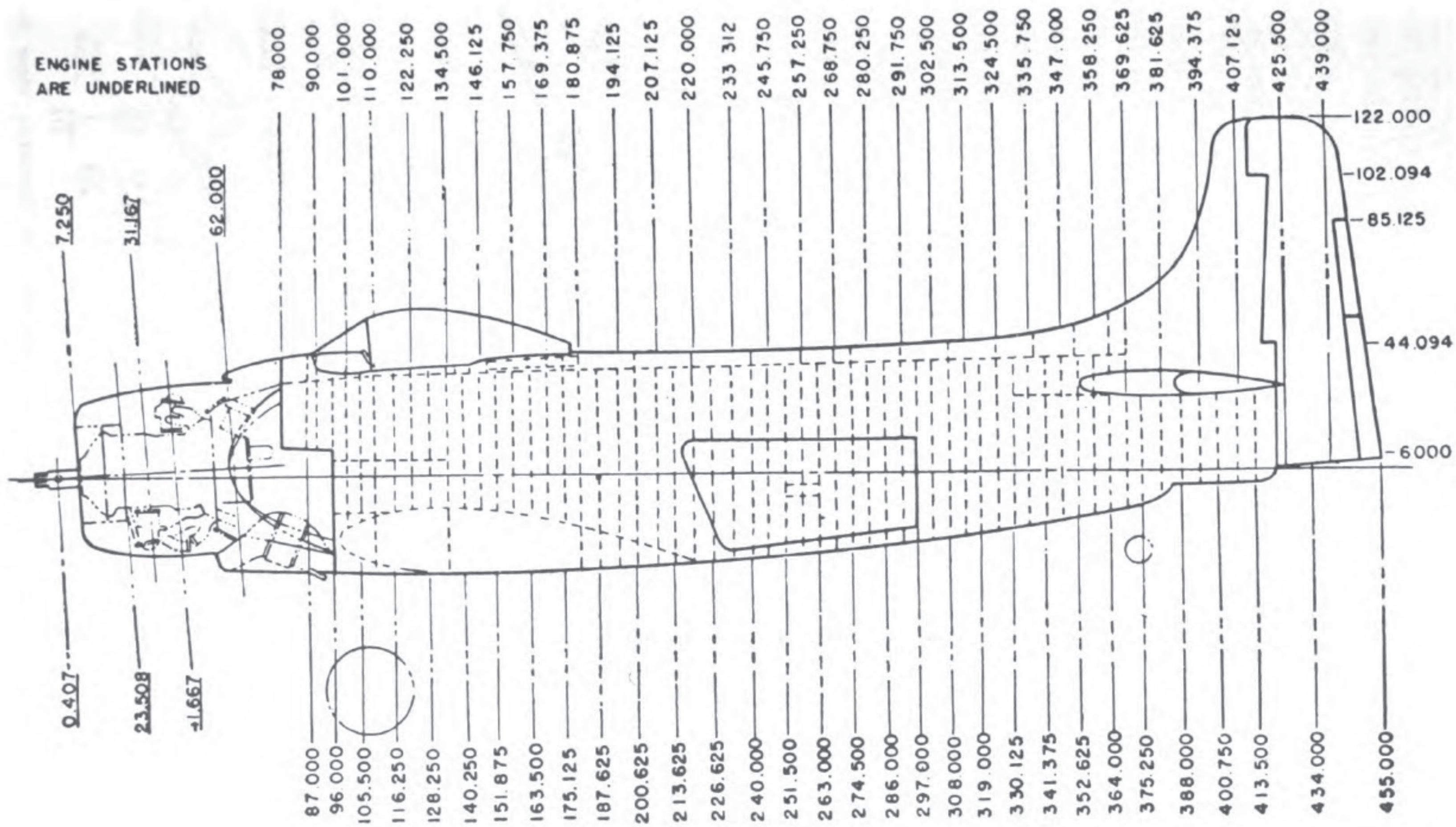


Figure 8–1.—Station marking—Continued.

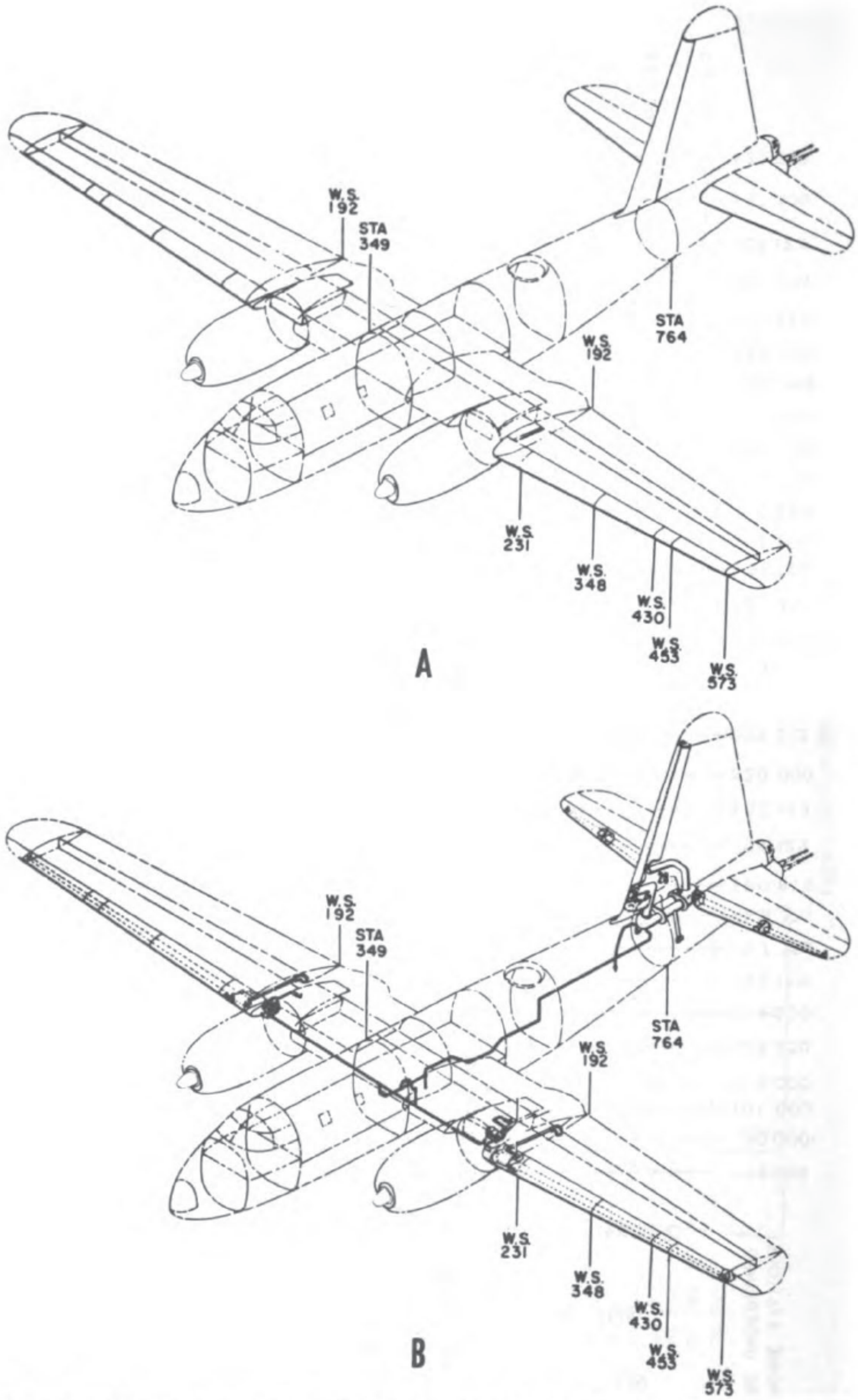


Figure 8–2.—A. Isometric outline of an airplane. B. Isometric view with de-icing system added.

drawing more clearly depict the article than the conventional orthographic projection. These drawings are of particular advantage when it is necessary to illustrate the installation of plumbing, wiring, or control linkage. However, with the curving lines and lack of parallelism, aircraft drawing is not considered easy even in orthographic projection, and the problems can be greatly magnified when an attempt is made to work in three dimensions. When three-dimensional drawings must be made, time can be saved and the work made easier if portions of new drawings, especially outlines, can be traced from other drawings and the appropriate additions drawn in. (See fig. 8-2.) A file of isometric outline drawings may be kept in the drafting room for this purpose.

Dimensions

Because of the large size of many drawings, dimensions should be made to read from the bottom. Dimensions are

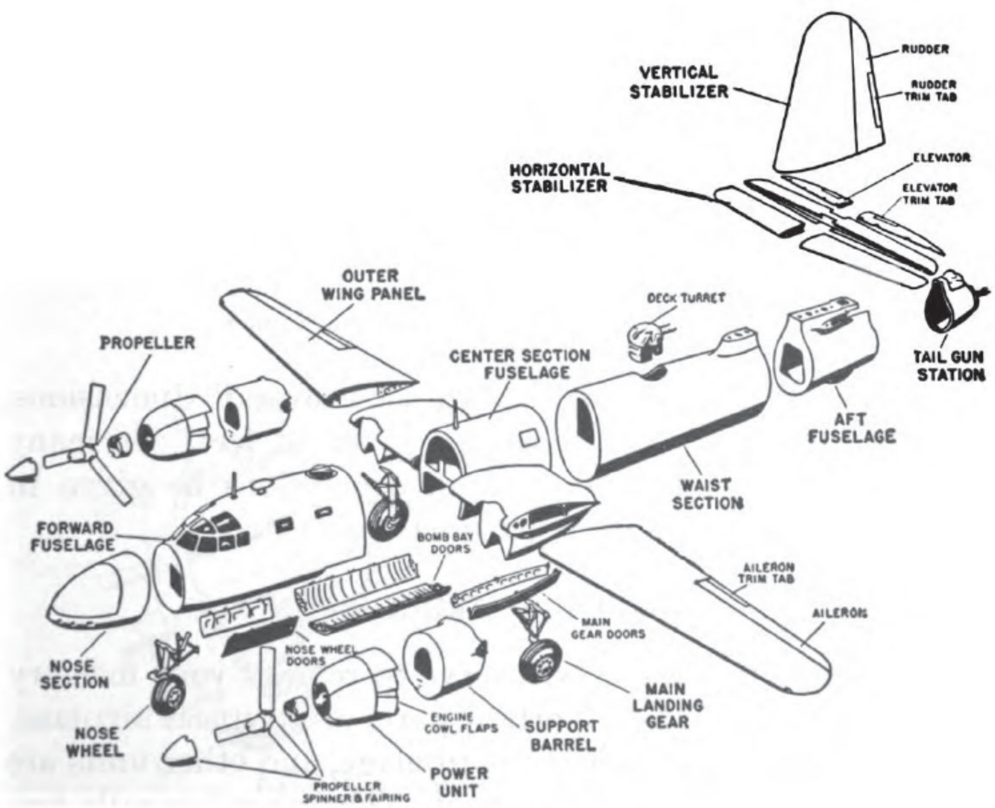


Figure 8-3.—Airplane nomenclature.

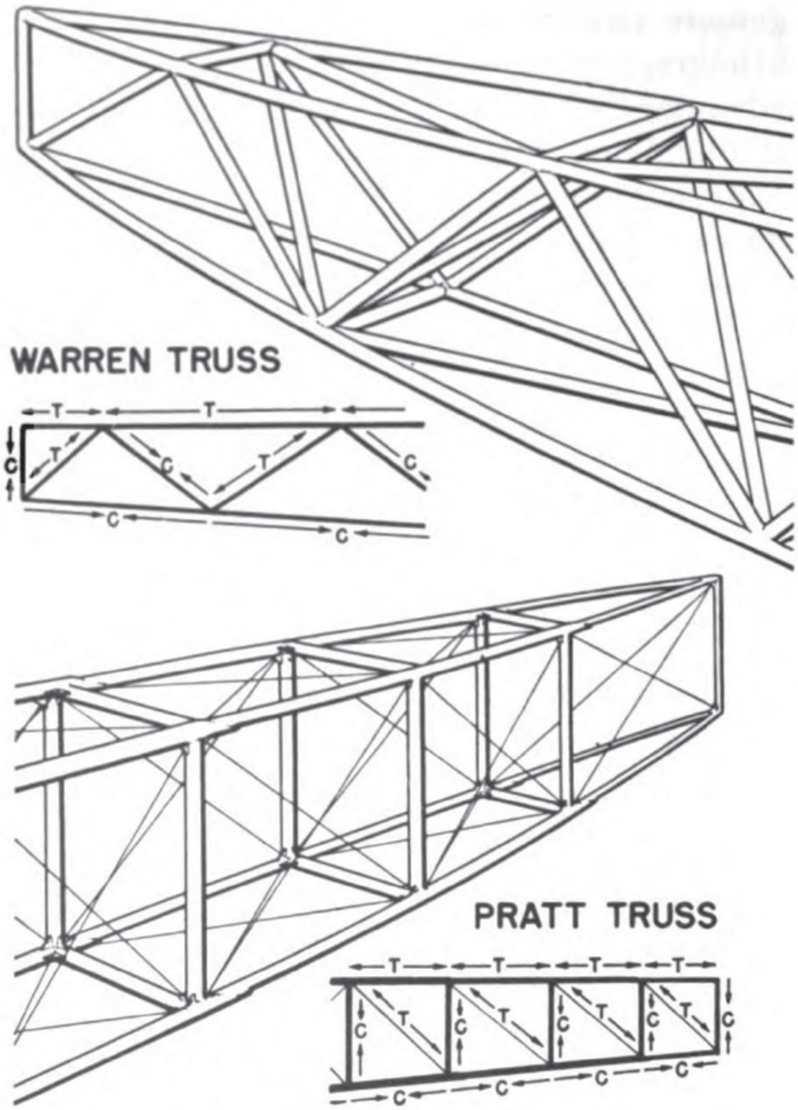


Figure 8–4.—Truss type fuselage construction.

usually given in inches although some overall dimensions, such as wing span, are sometimes given in feet. In many activities, it is preferred that all dimensions be given in decimals instead of in common fractions.

AIRPLANE STRUCTURE

A study of figure 8–3 will serve to refresh your memory with the names of the important parts of a typical airplane. The main structural unit is the fuselage, and other units are attached directly or indirectly to it. There are basically two

types, or principles, of construction, which are applied to aircraft, as well as some modifications or combinations of the two. These are the TRUSS TYPE of construction and the MONOCOQUE TYPE.

In the TRUSS TYPE of construction, metal tubing or wood is joined in a series of triangles or trusses similar to the trusses of building frame or bridge construction. (See fig. 8–4.) This framework is covered with cloth which later is saturated with a liquid called DOPE. When it hardens, dope greatly increases the strength and tautness of the cloth and also makes it impermeable to air and water. Most of the structural strength, however, is considered as coming from the

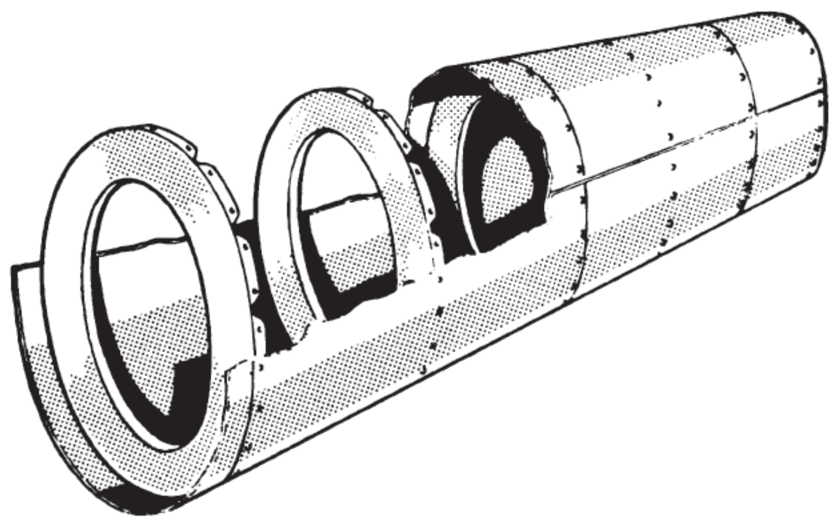


Figure 8–5.—Monocoque fuselage.

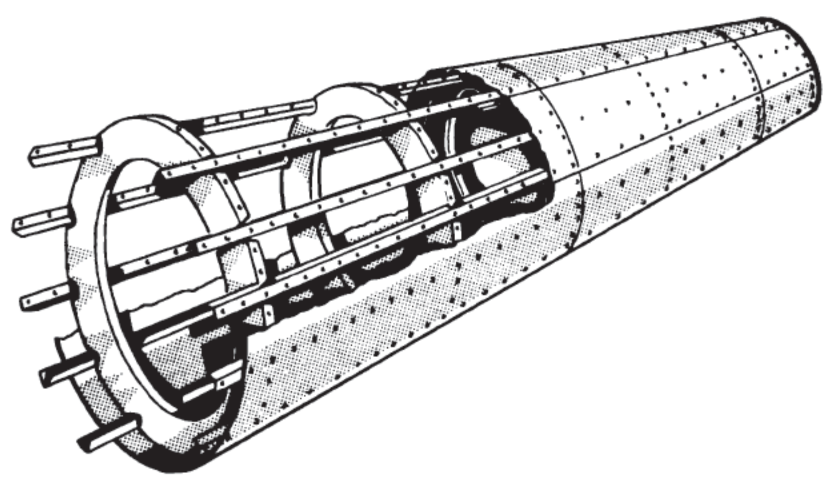


Figure 8–6.—Semimonocoque fuselage.

framework and not from the covering. Today this type of construction is rarely used except on small aircraft or on parts for larger planes.

The MONOCOQUE TYPE of fuselage relies largely on the metallic skin or shell for strength and rigidity. (See fig. 8–5.) The skin is reinforced and held in correct form by vertical rings, formers, and bulkheads.

Most military aircraft have what is known as SEMI-MONOCOQUE construction. In this type, part of the stress is borne by the shell and part by lengthwise members, called STRINGERS. (See fig. 8–6.)

A typical wing structure is shown in figure 8–7. Control surfaces, such as ailerons, elevators, and rudders, have structures similar to wings.

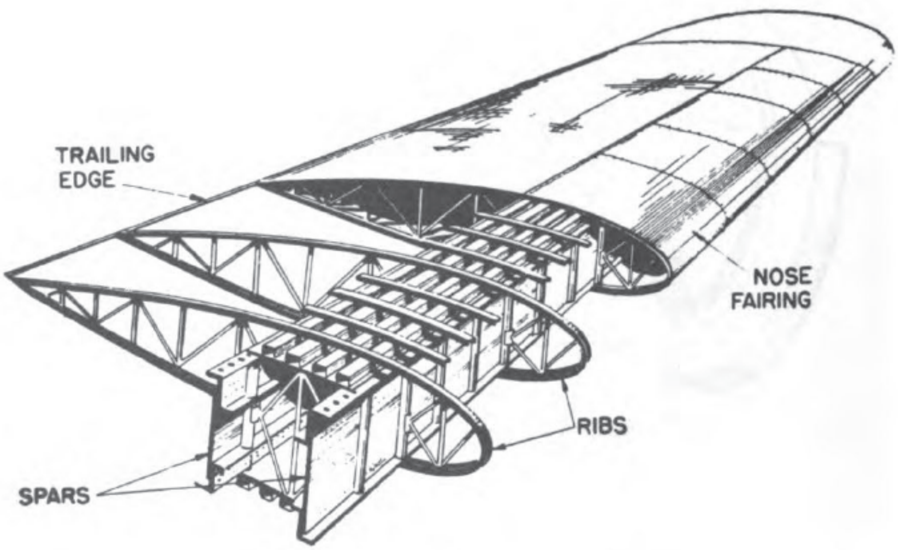


Figure 8–7.—Typical wing structure.

Figure 8–8 illustrates two types of engine mount. Although engine mounts vary greatly in appearance, depending on the size, type, and characteristics of the engine, the basic structural features are similar. Among the things which must be considered in the design are the thrust and torque of the propeller, the weight of the engine, and the vibration. Also, the engine and its equipment must be accessible for maintenance and inspection. Engine mounts are always

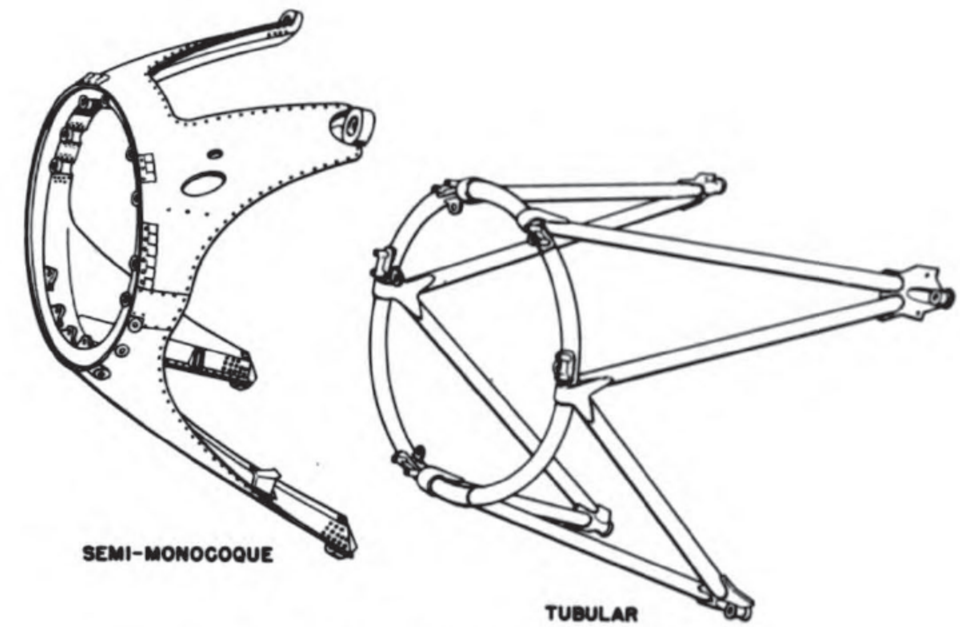


Figure 8–8.—Two types of engine mount.

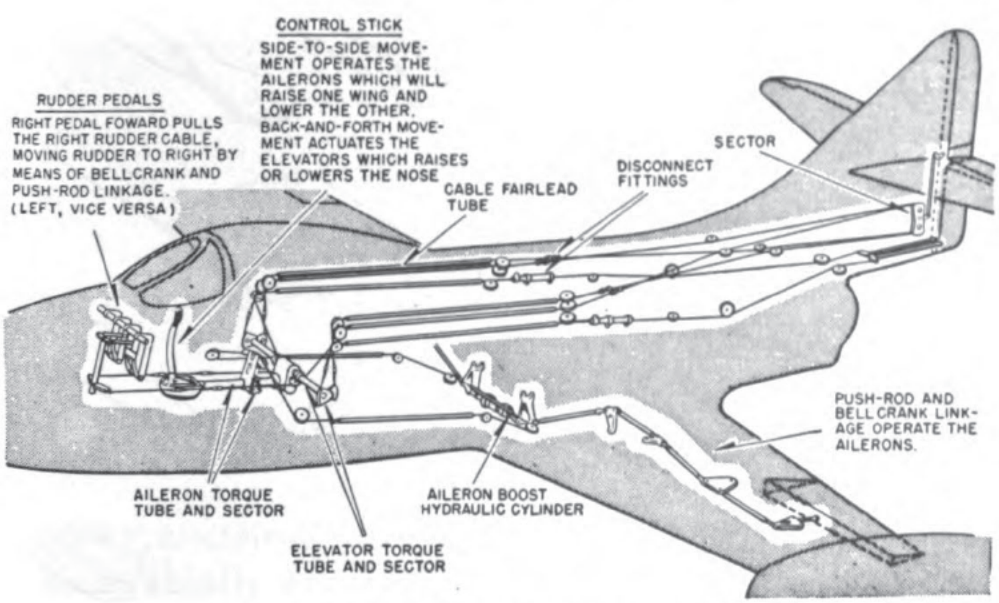


Figure 8–9.—Typical control system diagram.

Figure 8–10.—Control cable.

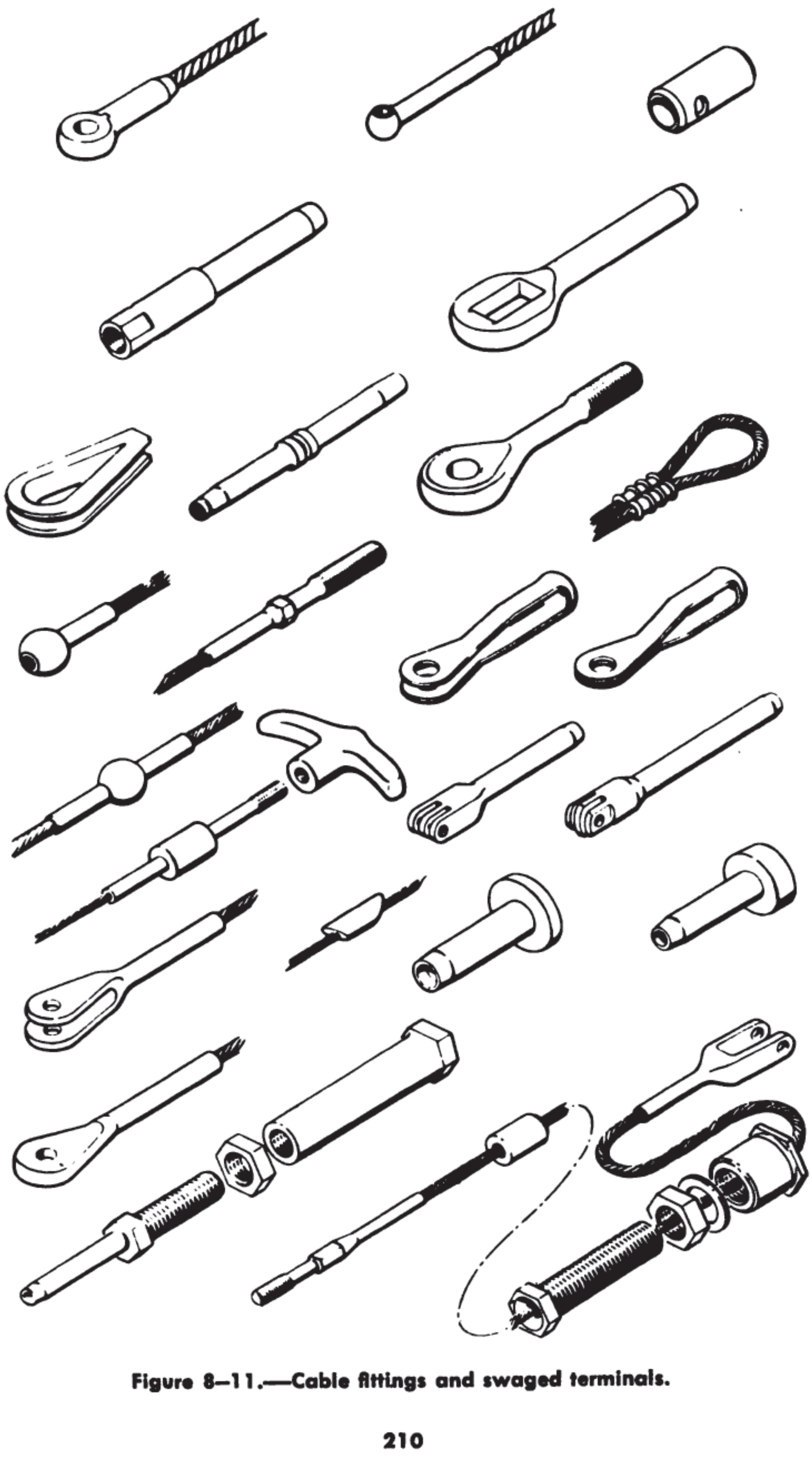


Figure 8-11.—Cable fittings and swaged terminals.

placed just forward of a flametight bulkhead, called a fire-wall.

A typical control system is illustrated in figure 8–9. The cables, rods, bell cranks, etc., which connect the controls to the control surfaces, are called the flight control linkage. Figures 8–10 and 8–11 illustrate types of cable, cable terminals, and cable fittings.

Most airplanes, with the exception of small, slow planes, have retractable landing gear. The wheels may be retracted toward the rear, inward toward the fuselage, or outward toward the wing tips. Retracting may be accomplished

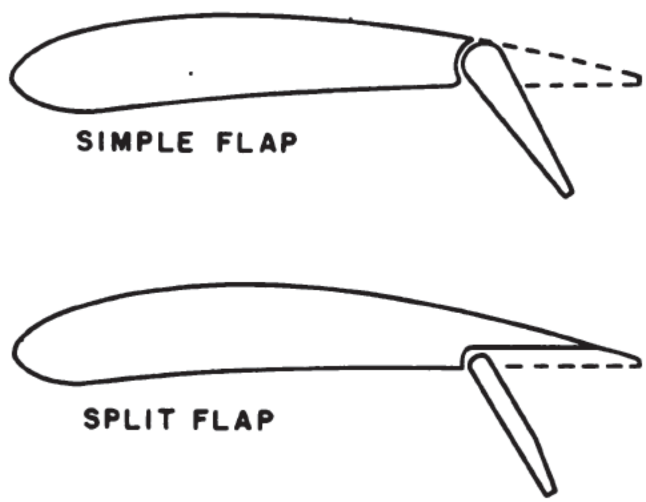


Figure 8–12.—Two basic types of flaps.

manually, electrically, or hydraulically. Usually electrically or hydraulically operated units have manual controls for emergency use.

Relatively large airfoils hinged to the trailing edge of the wings near the fuselage are called wing flaps. (See fig. 8–12.) When they are lowered, they increase both the lift and the drag of the wings. This enables the pilot to reduce the airspeed when the plane is descending and to approach a runway at a steeper angle than would otherwise be possible. This steeper descent results in a shorter landing roll. The

flaps can also be used to give extra lift to the wings when the plane is taking off.

MATERIALS

Every airplane is a compromise between two factors—weight and strength. Each pound of weight added to an airplane cuts down its flying efficiency. This relationship between the strength of a material and its weight per cubic inch is called the strength-weight ratio. The strength-weight ratio is one of the most important considerations in selecting various metals, woods, plastics, or other materials to be used in aircraft construction. Other highly important factors are resistance to corrosion and fatigue, and hardening or other physical changes that occur in the materials when they age.

Metals

The high strength-to-weight ratio, high resistance to corrosion, and comparative ease of fabrication have resulted in very extensive use of aluminum and its alloys. Wrought aluminum alloys are designated by a number followed by the letter "S." The number indicates the composition of each individual alloy. For example, 24S is an aluminum alloy containing approximately 92 percent aluminum with small amounts of manganese and magnesium. The purest form of commercial aluminum is approximately 99 percent and is designated as 2S. Following the letter S, there may be additional letters or numerals to indicate the kind of temper. For example, the letter T, often followed by one or more numerals, indicates that the metal has been heat treated and fully aged. The table in figure 8–13 lists some of the important aluminum alloys. Some important steels and their uses are listed in the table in figure 8–14. Magnesium came into wide use during World War II. When alloyed with small amounts of zinc, aluminum, and manganese, it has the highest strength-to-weight ratio of any of the commonly used metals.

NONSTRUCTURAL

Material and forms	Navy Specification No.	Alloy No.	Purpose
Aluminum sheet	47-A-2	2S	Welded tanks, junction boxes, and miscellaneous small parts.
Aluminum tubing	44-T-19	2S	
Aluminum rods, wire	46-A-3	2S	
Aluminum rivets	43-R-5	2S	
Aluminum coil	47-A-5	2S	
Aluminum welding wire	46-R-1	2S	
Aluminum alloy manganese:			
Sheet	47-A-4	3S	Welded tanks, junction boxes, and small parts
Tubing	44-T-20	3S	
Bars, rod, etc.	46-A-6	3S	
Rivets	43-R-5	3S	
Aluminum alloy manganese-magnesium:			Welded tanks, fuel, and oil lines.
Sheet	47-A-9	4S	Difficult shapes, welded, such as nose cowling, fairing, etc.
Tubing	44-T-24	4S	
Rods, bars, etc.	46-A-8	4S	
Welding rod	46-R-1	4S	
Aluminum alloy Cu-MG-MN-Cr:			
Sheet	47-A-11	52S	Cowling, fuselage, fairing, and streamlining, fuel and oil lines, etc.
Tubing	44-T-32	52S	

NOTE.—Alloy 52S is preferable to the above (2S, 3S and 4S) and should be used for the above purposes.

STRUCTURAL (HEAT-TREATED)

Aluminum alloy Al-Cu-Mg-Mn:			All structural shapes, frames, struts, skin (floats and hulls), wings, fuselages. Balancing surfaces, etc.
Sheet	47-A-3	17ST	
Tubing (round)	44-T-21	17ST	
Tubing (streamline)	44-T-22	17ST	
Bars, rods, wire	46-A-4	17ST	
Forgings	46-A-7	17ST	
Rivets	43-R-T	------	
Aluminum alloy Al-Cu-Mg-Mn:			
Sheet	47-A-10	24ST	
Bar, rod, shapes	46-A-9	24ST	

NOTE.—Alloy 24ST is preferable to 17ST and should be used for all structural purposes.

Figure 8-13.—Navy designation of and uses for aluminum alloy.

Alloy Steels

SAE No.	Alloy	Aircraft uses	Characteristics
2330	Nickel	Nuts and bolts	Strong and tough.
3140	Chrome-nickel	Heat treated forgings, crankshafts, connecting rods.	Strong and tough as compared to plain carbon steels.
3250	Chrome-nickel	Oil hardened parts to be machined and forged.	High physical properties.
4130	Chrome-molybdenum	Fittings, tubular members	Welds, high strength, tough.
4140	High carbon chrome-molybdenum.	Heavy parts	Responds to heat treatment better than 4130.
4340	Chrome-nickel-molybdenum	Crankshafts, propeller hubs	Good physical qualities.
6150	Medium carbon chrome-vanadium.	Springs, heat treated forgings	Limited structural uses.
6195	High carbon chrome-vanadium	Roller and ball bearings	Extremely hard.

51210	Chromium steel	Balls, races and anti-friction bearing rollers.	Hard.
51335	Chromium	(Stainless) Bomb shackles, pump shafts.	Corrosion resisting.

Carbon Steel

Class	Percentage or carbon	Typical SAE steels	General use
Low carbon	0.10–0.30	1025 (mild steel)	Forgings, low stressed fittings.
Medium carbon	0.30–0.50	1035 and 1045	Good machining qualities. Small and medium sized forgings. Structural steel.
High carbon	0.50–1.05	1095 (high Carbon)	Machine and hand tools.

Figure 8–14.—Steels used in aircraft.

Bends

Figure 8–15 illustrates some of the terms which apply to sheet metal bends. Note that the bend radius is always measured to the inside surface. The sharpest bend that can be put in a piece of metal without critically weakening it is the MINIMUM RADIUS OF BEND. The table in figure 8–16 gives

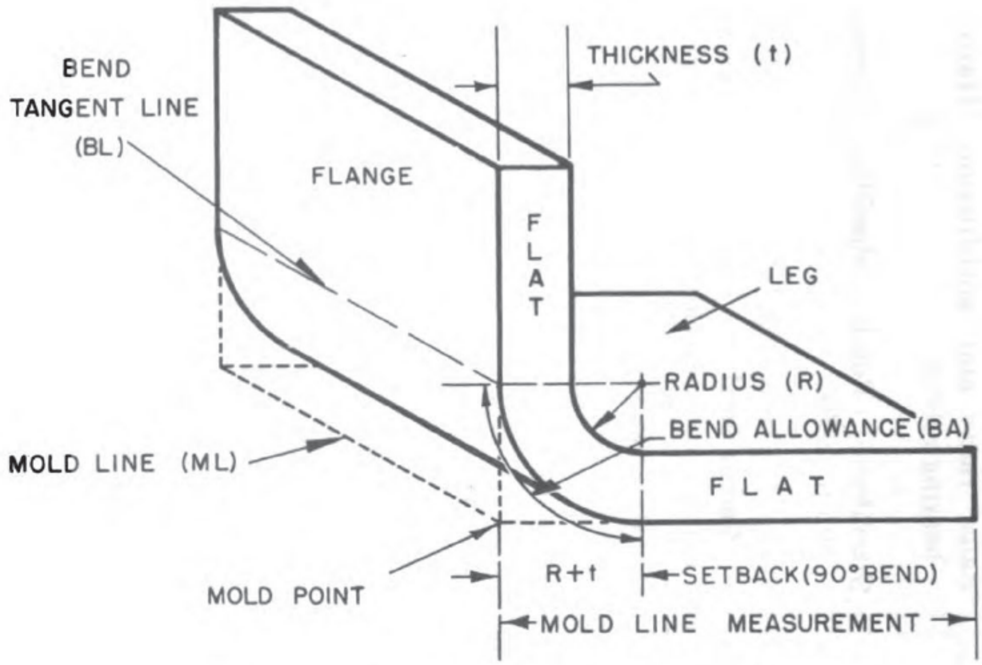


Figure 8–15.—Terms used in reference to bends.

the generally accepted minimum radius of bend for various alloys and thickness.

The length of metal to allow for a bend can also be found by consulting tables which may be found in most sheet metal handbooks. If you do not have access to a table giving these values, the allowance for a 90 degree bend can be estimated fairly closely by using a formula. Multiples or fractions of 90 degrees can also be computed from this formula. The formula is phrased thus,

$$A=\frac{\pi(R+\frac{1}{2}T)}{2}.$$

Minimum Bend Radii for Sheet Stock

STEEL SHEET		ALUMINUM ALLOY SHEET				
Annealed		Annealed Aluminum Alloy			H. T. Aluminum Alloy	
Thickness	Min. Radius	Thickness	Minimum Radius		Minimum Radius	
			Standard	Special	Standard	Special
.025	1/32	.016	1/64		3/32	3/64
.031	1/32	.020	1/64		3/32	3/64
.038	1/32	.025	1/32	1/64	1/8	1/16
.050	1/16	.032	1/32	1/64	1/8	1/16
.063	1/16	.040	1/16	1/32	3/16	3/32
.078	1/8	.051	1/16	1/32	3/16	3/32
.094	1/8	.064	1/8	1/16	1/4	1/8
.125	1/8	.072	1/8	1/16	1/4	1/8
.188	3/16	.081	1/8	3/32	1/4	
.250	1/4	.091	5/32	3/32	3/8	
		.102	3/16	3/32	3/8	
		.125	1/4	1/8	1/2	
		.188	3/8	3/16	3/4	
		.250	1/2	1/4	1	

The "Special" minimum radii for aluminum alloy sheet may be used where the bend is 90 degrees or less in special cases as, for example, where clearance for rivet or bolt heads or attached parts is necessary.

Figure 8–16.—Minimum bend radii for sheet stock.

In this formula,

R = radius,
T = thickness of metal,
A = allowance for 90 degree bend.

The relationship of these factors is illustrated in figure 8-17.

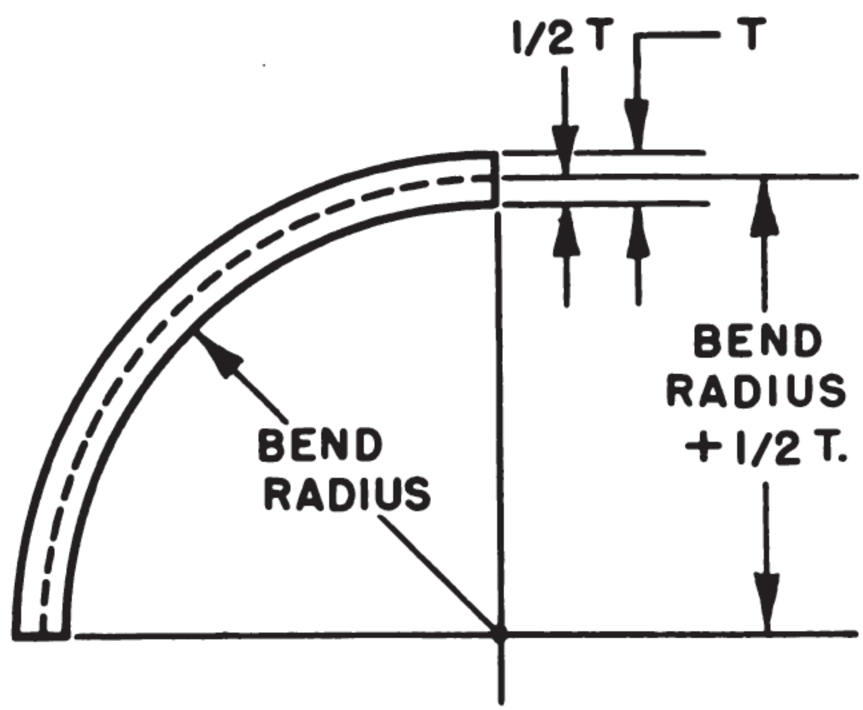


Figure 8-17.—Terms in bend allowance formula.

The amount of setback for any bend can be computed by the formula:

$$S=K(R+T).$$

In this formula,

S = setback,
R = radius,
T = thickness of metal,
K = constant.

For a 90 degree bend, K is equal to 1. In other words, the setback on a 90 degree bend is simply the radius plus the thickness of the metal. (See fig. 8-16.) The value of K for other angles can be found in the table in figure 8-18.

A°	K	A°	K	A°	K	A°	K
1	0.00873	46	0.42447	91	1.0176	136	2.4751
2	.01745	47	.43481	92	1.0355	137	2.5386
3	.02618	48	.44523	93	1.0538	138	2.6051
4	.03493	49	.45573	94	1.0724	139	2.6746
5	.04366	50	.46631	95	1.0913	140	2.7475
6	.05341	51	.47697	96	1.1106	141	2.8239
7	.06116	52	.48773	97	1.1303	142	2.9042
8	.06993	53	.49853	98	1.1504	143	2.9887
9	.07870	54	.50952	99	1.1708	144	3.0777
10	.08749	55	.52057	100	1.1917	145	3.1716
11	.09629	56	.53171	101	1.2131	146	3.2708
12	.10510	57	.54295	102	1.2349	147	3.3759
13	.11393	58	.55431	103	1.2572	148	3.4874
14	.12278	59	.56577	104	1.2799	149	3.6059
15	.13165	60	.57735	105	1.3032	150	3.7320
16	.14054	61	.58904	106	1.3270	151	3.8667
17	.14945	62	.60086	107	1.3514	152	4.0108
18	.15838	63	.61208	108	1.3764	153	4.1653
19	.16734	64	.62487	109	1.4091	154	4.3315
20	.17633	65	.63707	110	1.4281	155	4.5107
21	.18534	66	.64941	111	1.4550	156	4.7046
22	.19438	67	.66188	112	1.4826	157	4.9151
23	.20345	68	.67451	113	1.5108	158	5.1455
24	.21256	69	.68728	114	1.5399	159	5.3995
25	.22169	70	.70021	115	1.5697	160	5.6713
26	.23078	71	.71329	116	1.6003	161	5.9758
27	.24008	72	.72654	117	1.6318	162	6.3137
28	.25862	73	.73996	118	1.6643	163	6.6911
29	.25863	74	.75355	119	1.6977	164	7.1154
30	.26795	75	.76733	120	1.7320	165	7.5957
31	.27732	76	.78128	121	1.7675	166	8.1443
32	.28674	77	.79543	122	1.8040	167	8.7769
33	.29621	78	.80978	123	1.8418	168	9.5144
34	.30573	79	.82434	124	1.8807	169	10.385
35	.31530	80	.83910	125	1.9210	170	11.430
36	.32492	81	.85408	126	1.9626	171	12.706
37	.33459	82	.86929	127	2.0057	172	14.301
38	.34433	83	.88472	128	2.0503	173	16.350
39	.35412	84	.90040	129	2.0965	174	19.081
40	.36397	85	.91633	130	2.1445	175	22.904
41	.37388	86	.93251	131	2.1943	176	26.636
42	.38386	87	.94896	132	2.2460	177	38.188
43	.39391	88	.96569	133	2.2998	178	57.290
44	.40403	89	.98270	134	2.3558	179	114.590
45	.41421	90	1.00000	135	2.4142	180	Infinite

Figure 8–18.—*K* chart for computing setback.

Rivets

Riveting and spot-welding are two of the most common methods of joining sheet metal parts. A description of welding processes can be found in MIL–STD–20, *Military Standard Welding Terms and Definitions.*

The rivets used in airplane construction are usually solid shank rivets, obtainable with one of the types of heads pictured in figure 8–19. The round-head type is used on thick sheets where head bearing area is not too important, but where great head strength is desirable. The brazier-head type is more suitable for thin sheets because of its large area. For this reason, and because it offers little wind resistance, it is used extensively for riveting skin sheets. The countersunk-head type is used for riveting sheets over which other plates must fit. This type is also often used where heads are exposed to the slip stream. The flat-head type is sometimes used for internal riveting where increased clearance is re-

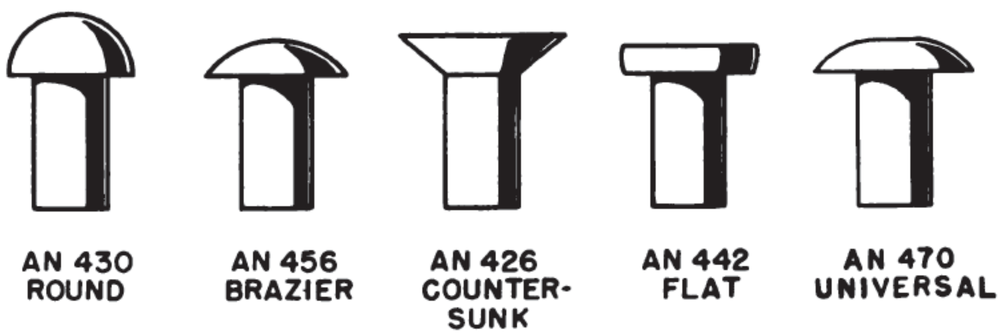


Figure 8–19.—Basic head shapes of rivets.

AN430AD-4-5——Length in 16ths
Diameter in 32nds
Alloy (A17S)
Head Shape (round)
Army-Navy

Note: Observe the position of the dashes in the example and be consistent in their use.

Figure 8–20.—A–N rivet coding example.

quired. The universal-head type is now extensively used in place of other protruding head types.

The system of letters and numerals used by the Navy and Air Force for coding rivets is illustrated in figure 8–20.

The four kinds of aluminum alloy usually used in aircraft rivets are designated by the following code letters:

2S and 3S	none or A
17S	D
24S	DD
A17S	AD

Rivets of each alloy are identified by the markings on the head, as illustrated in figure 8–21.

Figure 8–21.—Rivet identification markings.

Roughly speaking, rivets are chosen of material similar to the material which is to be joined by them. The A17ST is popular for riveting aluminum alloy structures. It has high resistance to corrosion and high shear strength, and it can be used in the condition in which it is received without further heat treating.

The required diameter of a rivet is determined largely by the thickness of the material. A large rivet in a thin sheet might result in an undesirable bulging of the thin material around the rivet head. On the other hand, too small a rivet would not have sufficient shear strength to carry the load. It is considered best for the diameter of a rivet to be no less than the combined thickness of the component parts of the joint. Very few rivets are used that are over $\frac{5}{16}$ inch in diameter. Rivets smaller than $\frac{3}{32}$ inch should not be used on any structural parts that carry stresses.

G = GRIP (TOTAL THICKNESS)
D = DIAMETER OF RIVET USED
$1\frac{1}{2}D + G$ = TOTAL LENGTH OF RIVET

Figure 8–22.—Correct rivet length.

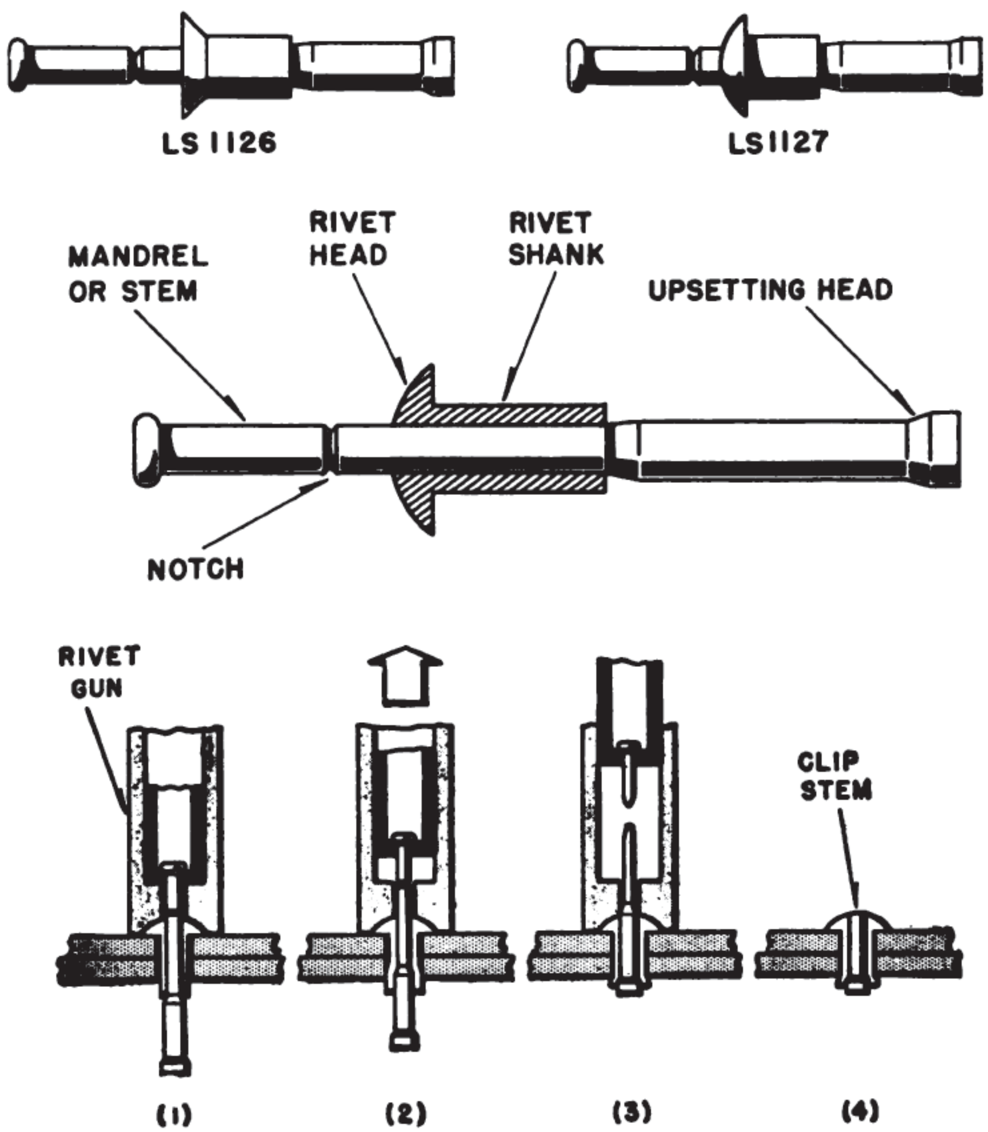


Figure 8–23.—Cherry rivets and the method of installing them.

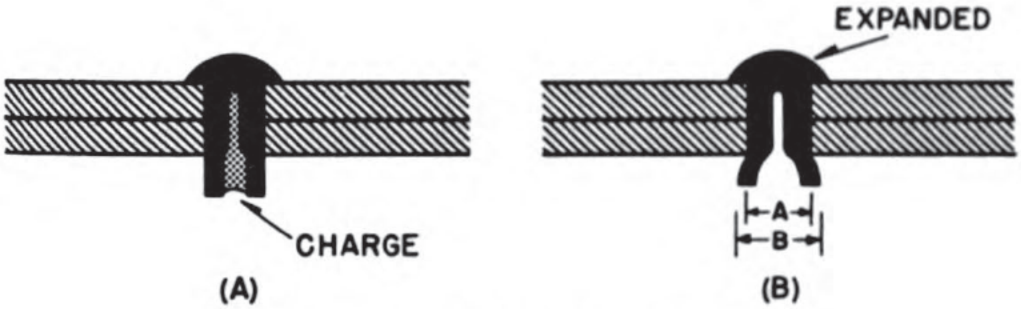


Figure 8–24.—Explosive rivets.

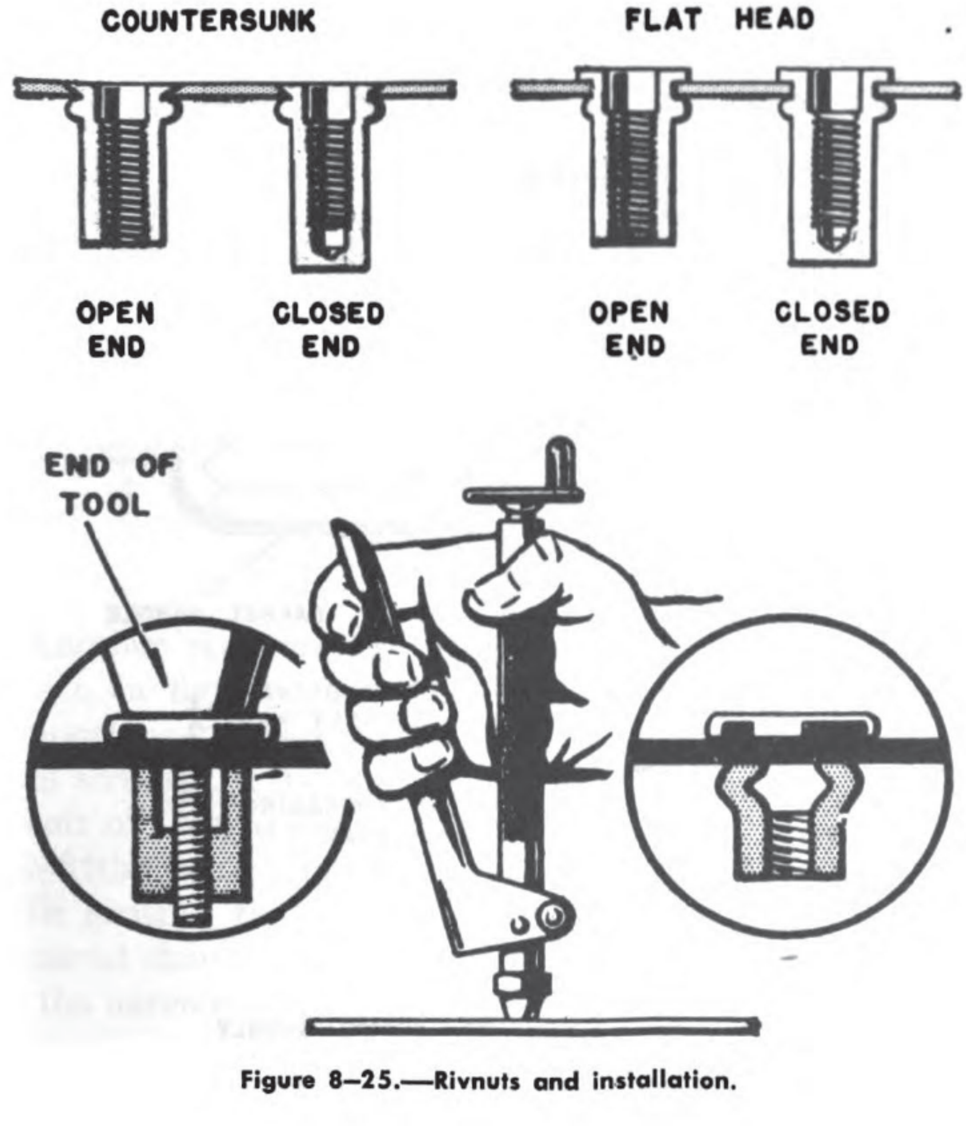


Figure 8–25.—Rivnuts and installation.

The length of a rivet should be equal to the combined thickness of the parts plus approximately $1\frac{1}{2}$ the rivet diameter. (See fig. 8–22.)

There are many places in an airplane where access to both sides of a riveted structural part is impossible or where space is too limited for a rivet to be headed in the usual manner. Furthermore, in the attachment of many nonstructural parts,

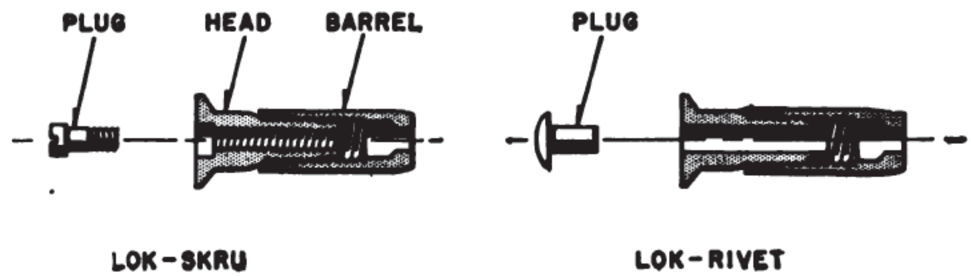


Figure 8–26.—Lok-screw and lok-rivet.

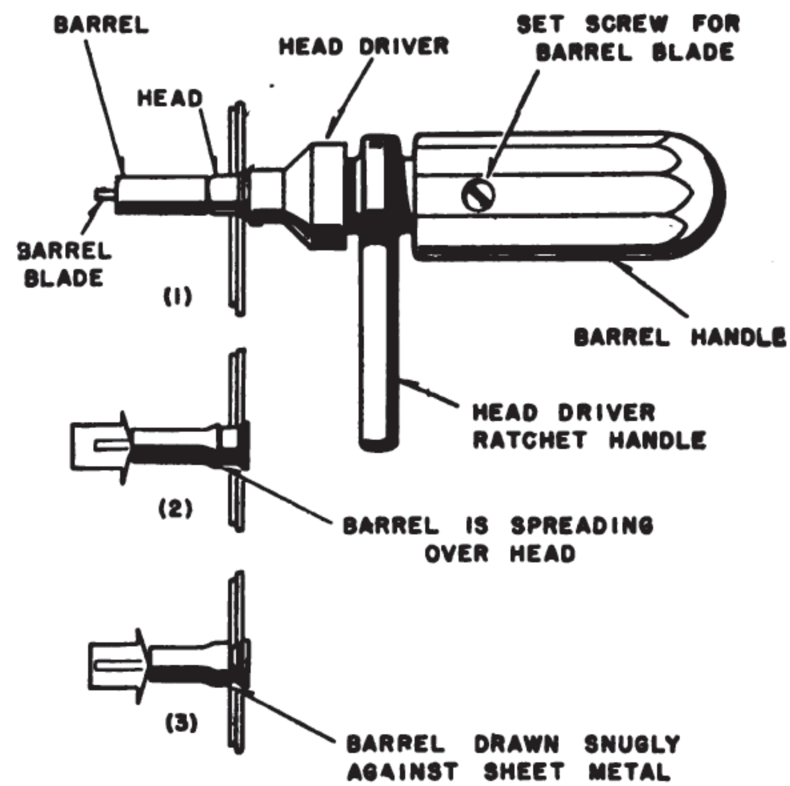


Figure 8–27.—Tools and steps for lok-rivet installation.

the full strength of solid shank rivets is unnecessary, and their application would add much extra weight. For use in such places, rivets have been designed which can be bucked from the accessible side and are lighter than solid shank rivets. Four such rivets and their application are illustrated in figures 8–23, 8–24, 8–25, 8–26, and 8–27.

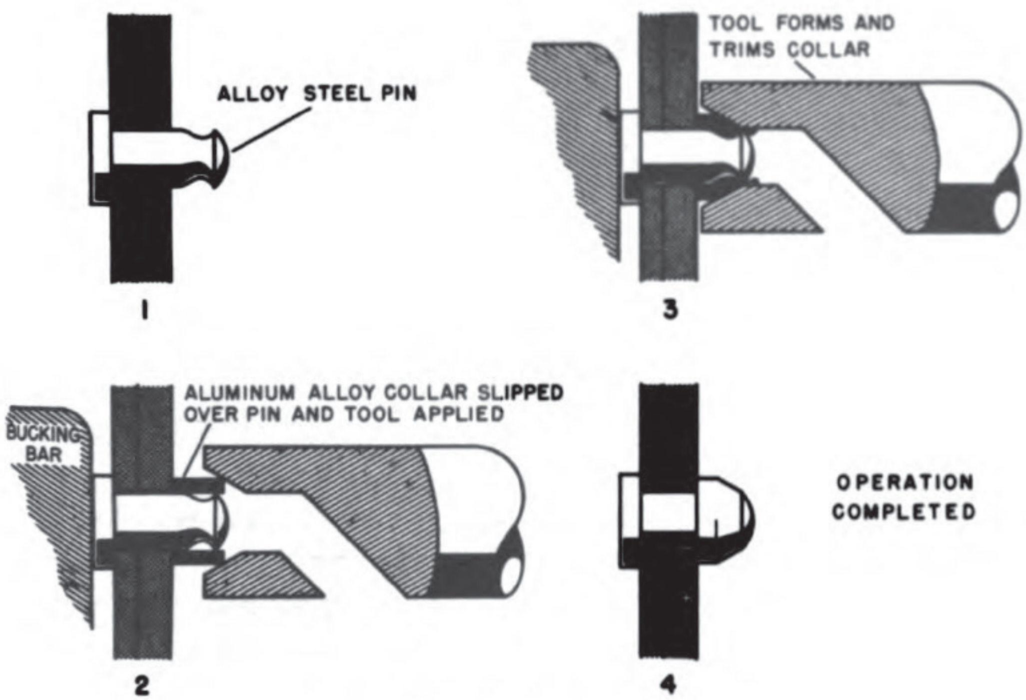


Figure 8–28.—Hi-shear rivet.

Another rivet worthy of mention is the Hi-shear rivet shown in figure 8–28. These rivets have the same shear strength as comparable sizes of AN hexagon head bolts or steel screws, but they are lighter and require less space than a bolt of comparable strength. Installation time is about one-fifth of that required for bolts.

In general, the spacing of rivets where a part is being repaired should conform to that used by the manufacturer in the surrounding area. The EDGE DISTANCE, or distance from the center of the first rivet to the edge of the sheet, should not be less than two rivet diameters or more than four.

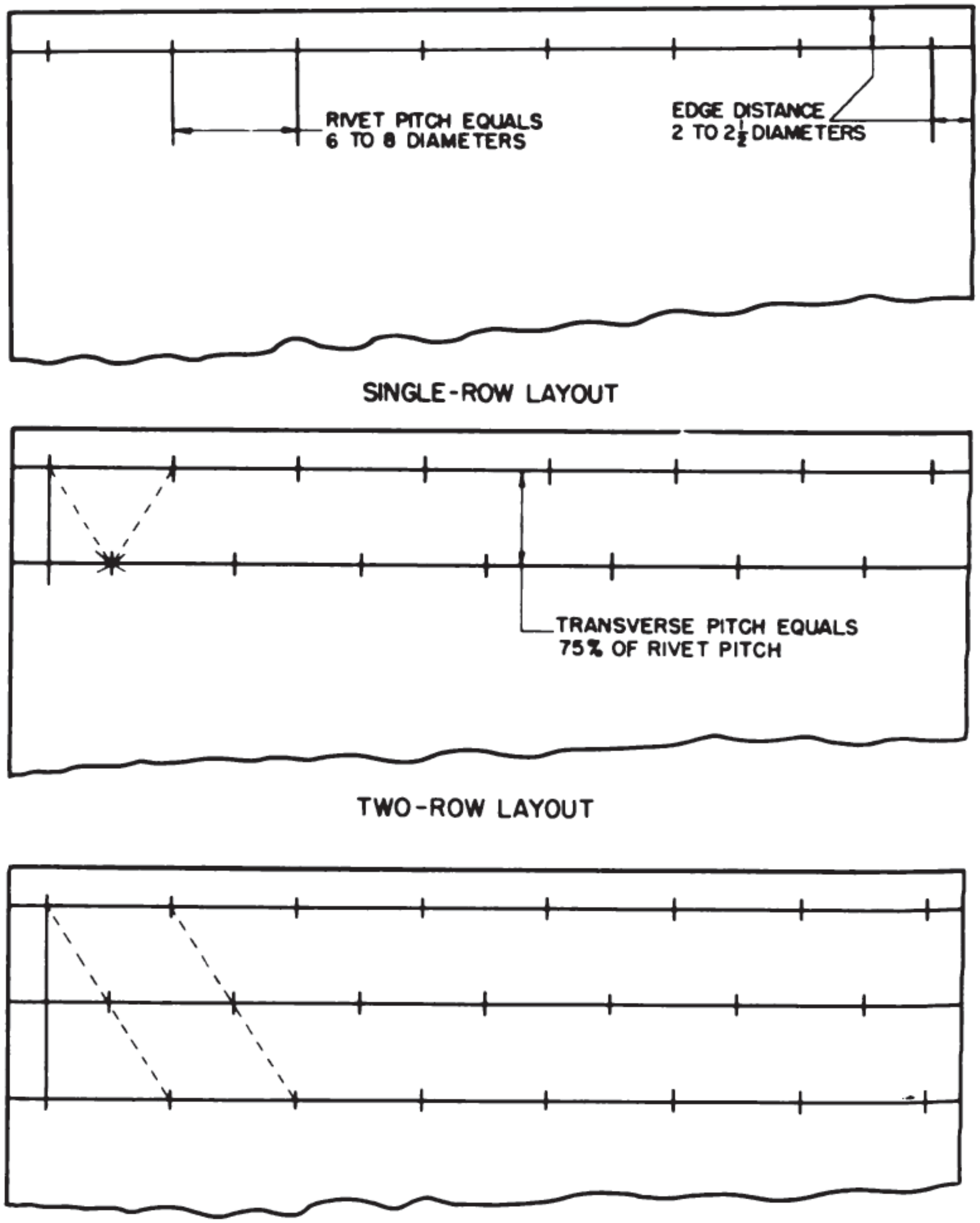


Figure 8–29.—Rivet spacing.

About 2½ rivet diameters is the distance recommended. The average rivet PITCH ranges from 6 to 8 diameters. TRANSVERSE PITCH is the distance between the rivet rows and is usually equal to 75 percent of the rivet pitch. The smallest allowable transverse pitch is 2½ rivet diameters. Figure

8–29 shows how rivets are spaced in a single-row, a two-row, and a three-row pattern.

Bolts

Aircraft bolts are used to join parts which are under very high tension, parts where repeated dismantling is necessary, or parts which are unsuitable for welding, riveting, or other means of fastening. Aircraft bolts are usually made of cadmium- or zinc-plated nickel steel, phosphor-bronze, or aluminum alloy.

Bolts are classed as AN general purpose, AN close tolerance, and AN special purpose bolts, or as NAS bolts. AN stands for Air Force-Navy and NAS for National Aircraft Standard. Most bolts belong to the AN group. Aircraft manufacturers sometimes make up bolts of different dimensions or higher strength qualities than either the AN or NAS bolts can give. These bolts are made for a particular application. It is important therefore that such bolts be replaced only by like bolts, designated by a part number.

Markings on the head of a bolt indicate both type and material, and whether it is AN or NAS. (See fig. 8–30.) Additional information, such as bolt diameter, bolt length, and grip length, may be obtained from a standard part numbering system. Unless otherwise indicated, all thread sizes on aircraft bolts are of the National Fine (NF) series.

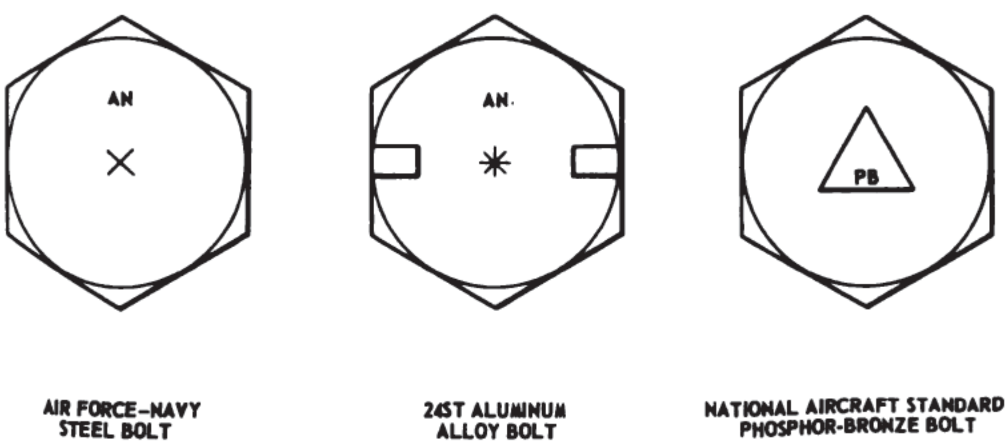


Figure 8–30.—Bolt-head markings.

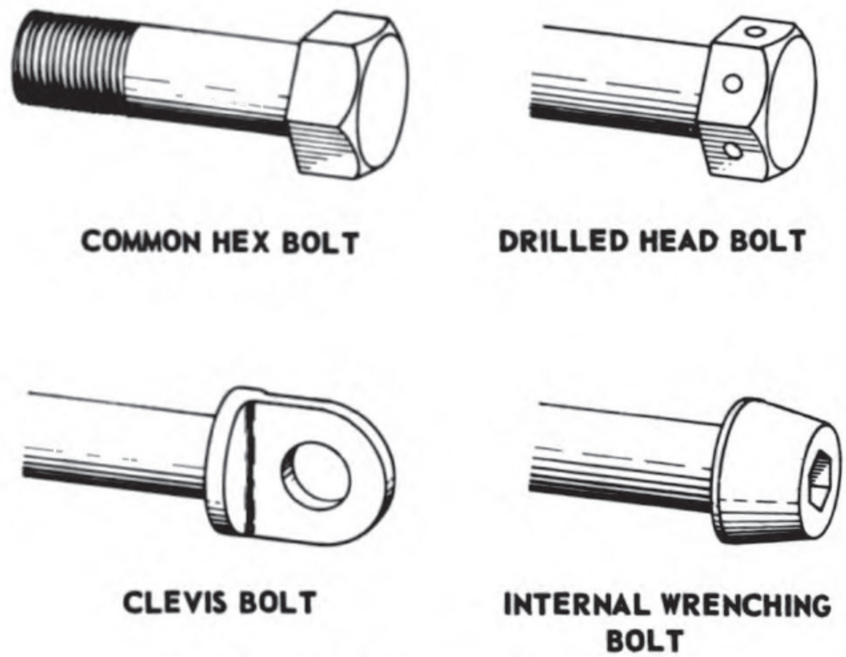


Figure 8–31.—Bolt types in general use.

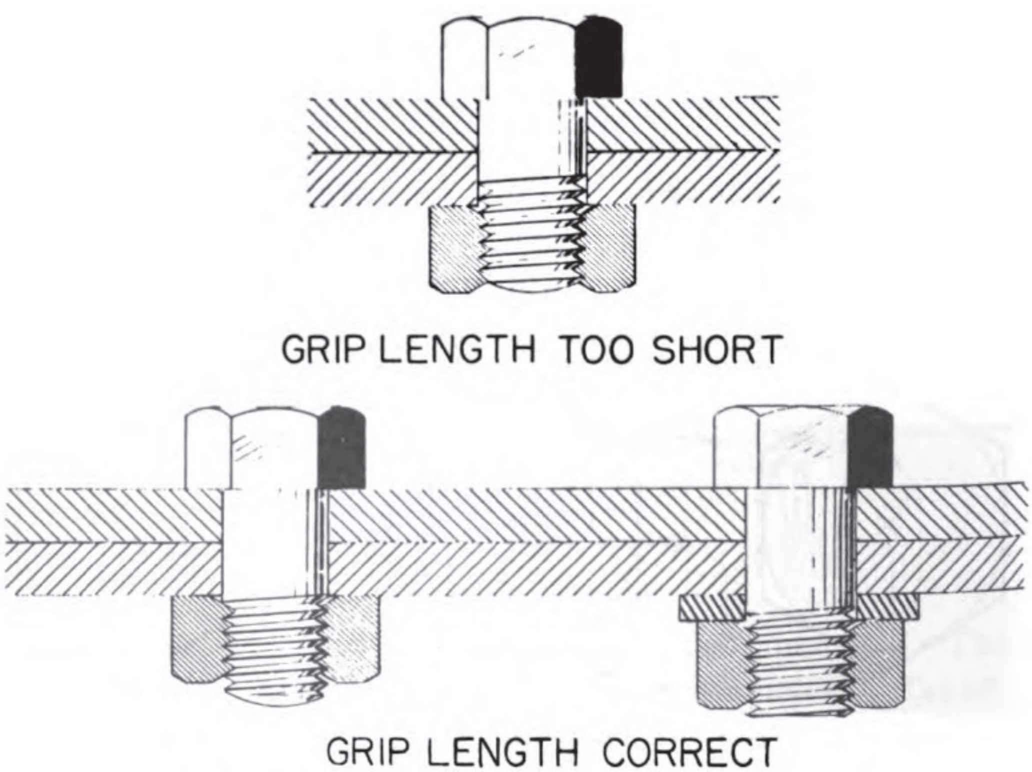


Figure 8–32.—Correct and incorrect bolt length.

Figure 8–31 shows some important types of bolts. When a bolt is selected, its grip length should equal the thickness of the materials to be bolted together and no part of the threads should bear on the material. If the grip length exceeds the thickness of the material, a washer may be used, as shown in figure 8–32.

Aircraft Nuts

Nuts do not accompany bolts when the bolts are ordered. The nuts must be ordered separately. No identifying markings or lettering appears on the nuts. They can be identified only by appearance. Except for a few very special types, nearly all aircraft nuts are Air Force-Navy Standard.

Aircraft nuts can be divided into two general groups: (1) non-self-locking nuts, which must be made safe by external locking devices, such as lock washers, cotter pins, or safety

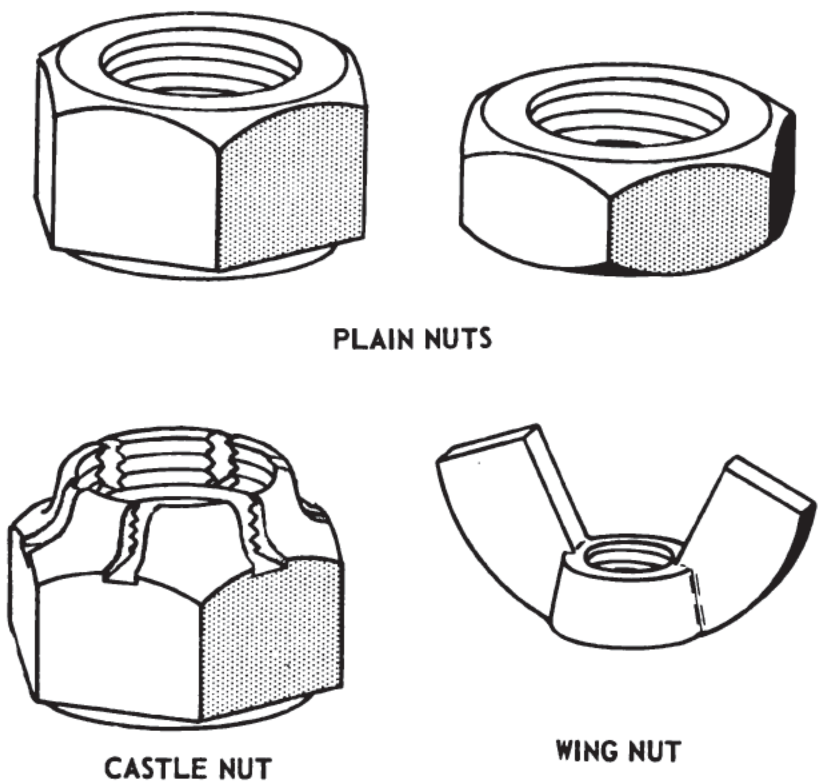


Figure 8–33.—Non-self-locking nuts.

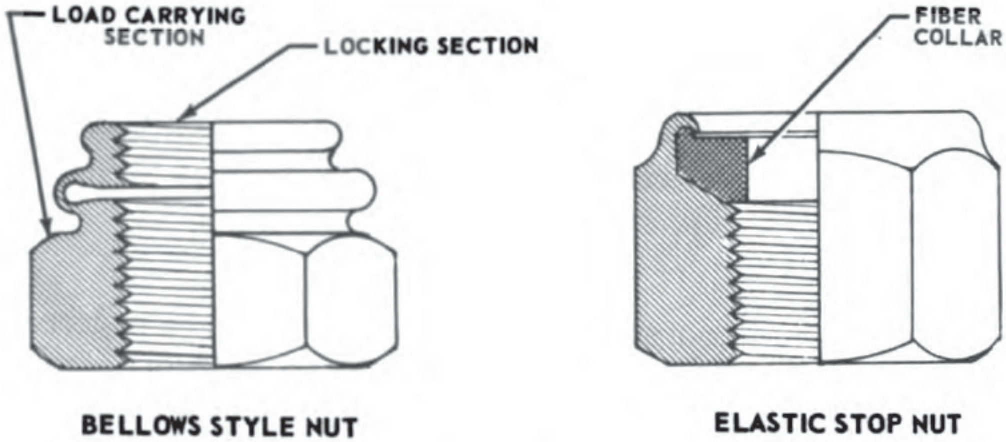


Figure 8–34.—Self-locking nuts.

wire and (2) self-locking nuts, which contain the locking feature as an integral part. (See figs. 8–33 and 8–34.)

Aircraft Screws

Screws are the most common form of threaded fastening devices used on aircraft. Generally, they differ from bolts in that they are made of lower strength material, they can be installed with a looser thread fit, the head shapes are formed to engage a screwdriver or a wrench, and the shanks have no clearly defined grip or may even be threaded along their entire length.

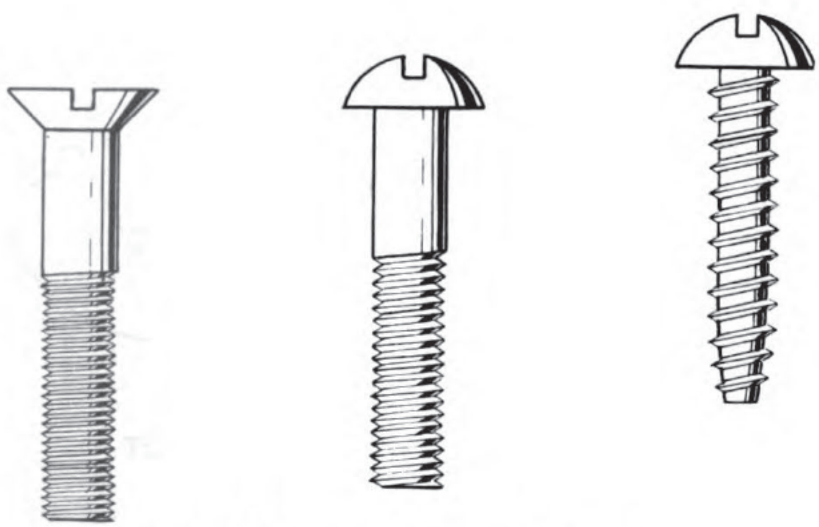
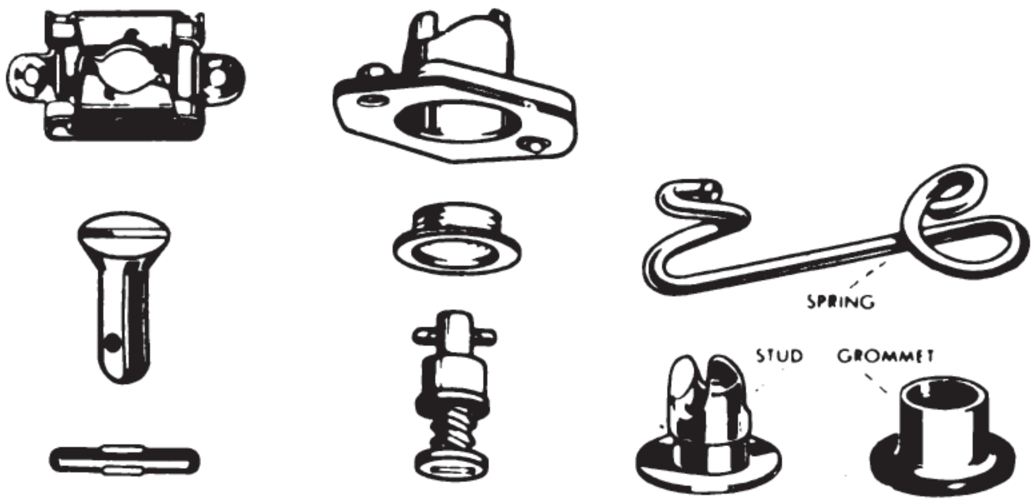


Figure 8–35.—Screws used in aircraft.

Screws may be classified roughly into three groups: (1) structural screws, which have the same strength as equivalent size bolts; (2) machine screws, which include the majority of types used for general-purpose repair and maintenance of aircraft; and (3) self-tapping screws, which may be used for attaching lighter weight, nonstructural parts. (See fig. 8–35.)



Airloc fastener. *Camloc fastener.* *Dzus fastener.*

Figure 8–36.—Cowling fasteners.

Cowling Fasteners

Cowling fasteners are used extensively in airplane construction for attaching cowling and fairing, and for fastening the doors of baggage compartments, inspection openings, access doors, and the like. They usually consist of a spring assembly, a stud, and a grommet. The spring serves as a tightening device and safety feature. Three approved cowling fasteners in common use on aircraft are the Dzus, the Camloc, and the Airloc. (See fig. 8–36.)

Plumbing Lines

Aircraft plumbing lines may be made of metal tubing and fittings or of flexible hose. Metal tubing and fittings are

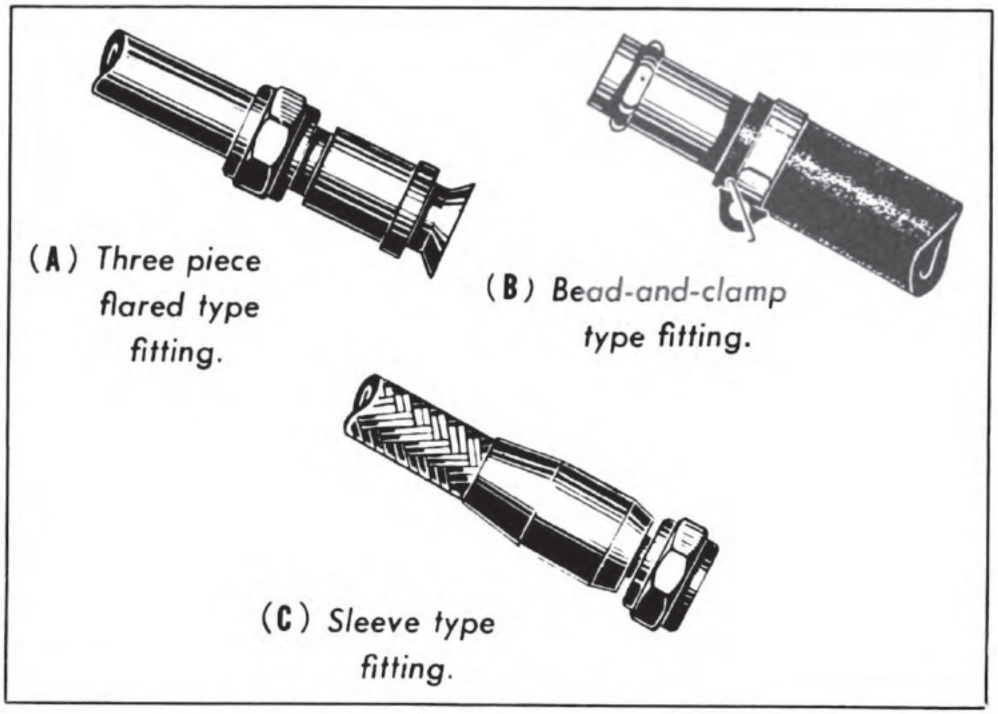


Figure 8–37.—A. Three-piece flared type fitting. B. Bead-and-clamp-type fitting. C. Sleeve-type fitting.

used in high pressure or critical systems while flexible lines are generally used in low pressure systems and for the attachment of units that are subject to vibration.

Copper tubing on aircraft has been largely superseded by aluminum alloy or steel tubing. The high fatigue factor of copper tubing is the chief reason for its replacement. It becomes hard and brittle from vibration and finally breaks. The characteristics of workability and resistance to corrosion, coupled with the light weight of aluminum alloy, have been major factors in the adoption of aluminum alloy. In some special high pressure hydraulic installations for the operation of landing gear, flaps, brakes, and the like, annealed corrosion-resistant steel tubing is often used. External brake lines are often made of steel tubing, because it can better withstand damage caused by thrown stones or by accidents in ground handling. Furthermore, since the flared section of steel tubing becomes somewhat stronger with cold-working and strain-hardening during the flaring process,

and since its higher tensile strength permits the use of tubing with thinner walls, the final installation weight is not very much greater than that of the thicker-walled aluminum-alloy tubing.

Three types of plumbing connectors, which are in general use for attaching pieces of tubing to other tubing or to system units, are illustrated in figure 8-37. Pressure in the system is usually the deciding factor as to which connector should be used. The beaded type of joint, which requires a bead, a section of hose, and hose clamps, may be used only in low or medium pressure systems, such as vacuum, fuel, oil, and coolant systems, and in low pressure hydraulic systems.

Bonding clamps secure lines to the airframe or to the strut assembly. (See fig. 8-38.) The rubber cushioned clamp is for lines which are subject to vibration. The cushion prevents chafing of the tubing. The plain clamp is for lines that are not subject to vibrations.

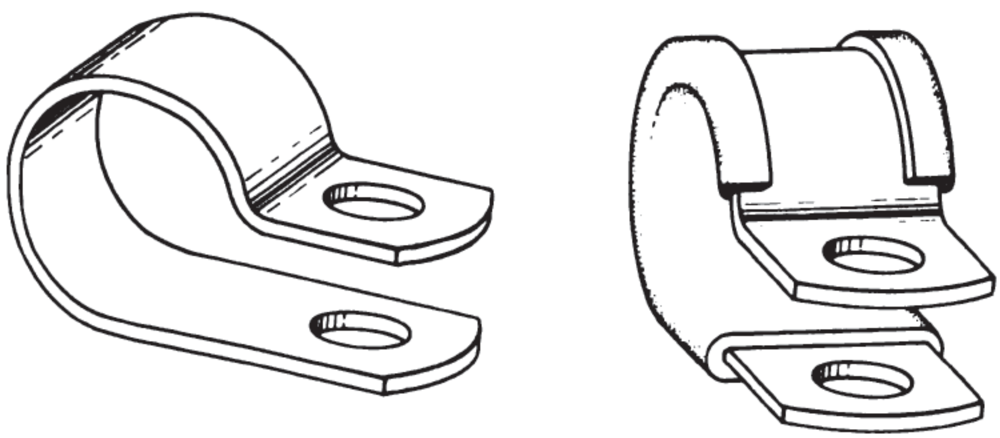


Figure 8-38.—Bonding clamps.

A direct straight line connection should never be made between two fixed attachment points, as bends are necessary to permit the tubing to expand or contract under temperature changes, and to absorb vibration. (See fig. 8-39.) Figure 8-40 shows the minimum distance for locating bends from the ends of tubing.

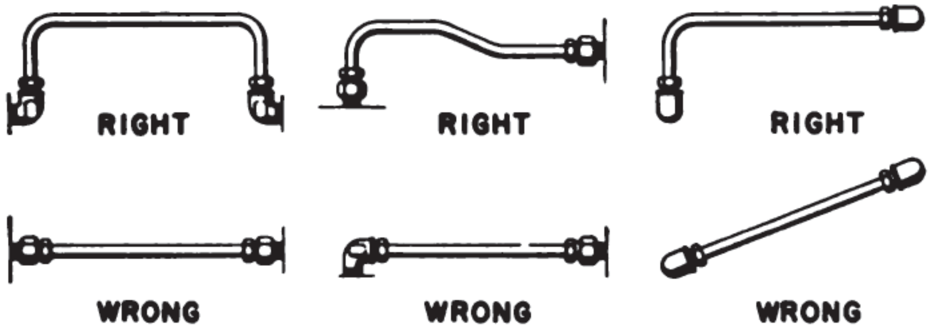


Figure 8–39.—Right and wrong methods of installing tubing and fittings.

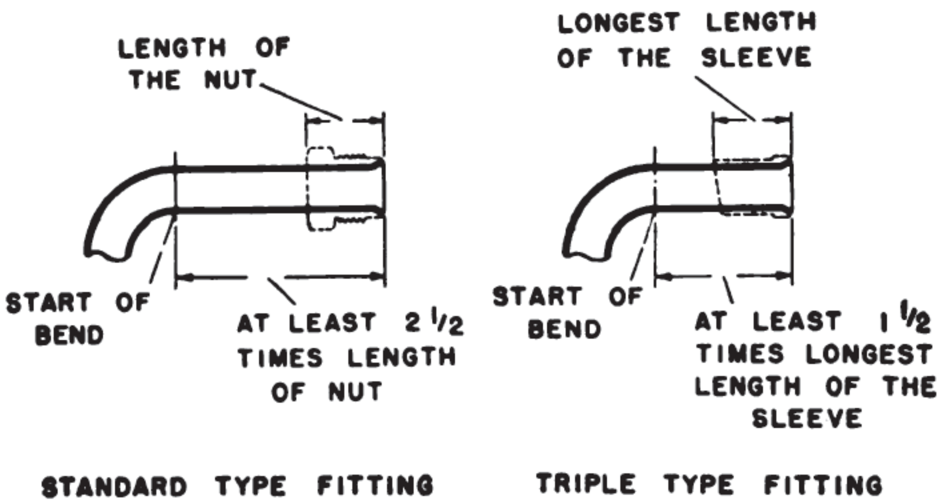


Figure 8–40.—Locating bends in tubes.

The minimum desirable or minimum allowable bend radii for various kinds of tubing can be obtained from tables, such as the one in figure 8–41. Too sharp a bend will cause a tube to flatten and may cause wrinkling, kinking, or cracking of the tube material, especially if proper tools are not available and bending has to be done by hand.

SPECIAL DRAWING METHODS

An object with complex curvature, such as the hull of a ship or the fuselage of an airplane, cannot be fully illustrated and dimensioned in simple orthographic views. In practice, whenever it is necessary to show surface curvature, contour lines at various station points are drawn on a single drawing, in a manner somewhat similar to the way hill contours are shown on a map.

TUBE MATERIAL	OUT-SIDE DIA. (Inch) Incl.	WALL THICK-NESS (Inch) Incl.	MINIMUM BEND RADIUS O. D. x Factor Below		METHOD OF BENDING (See legend below)					HEAT TREATMENT	
					NO FILL-ING	FILL WITH					
						SAND		RESIN	Spec. 11078 or other Low Temp Fusing Alloy	BEFORE BENDING	AFTER BENDING
			Struc-tural Use	Piping Fluids		Coarse	Fine				
Aluminum and 52 Aluminum Alloy	0.25 1.50	.032 .051		3	#3		#1 or #2		#4 or #5 #1 or #2		
	1.625 3.000	.057		3			#1 or #2				
17 and 24 Aluminum Alloy	0.25 2.00	.022 .065	6	4	#3		#1 or #2		#4 or #5 #1 or #2	Anneal or Ht. Treat	Heat Treat
	2.25 3.75	.065 .120	6	4			#1 or #2			Anneal or Ht. Treat	Heat Treat
Brass			5	4	#3			#1 or #2	#1 or #2		Anneal
Copper	0.125 1.125	.035 .049	3	3	#3		#1 or #2	#1 or #2			Anneal
Copper, Silicon, Bronze			3	3	#3		#1 or #2	#1 or #2			Anneal
1025 Steel	0.125 1.50	.028 .065	5	3	#5	#6				Torch	Normalize
	1.625 4.000	.065	5	3		#6				Torch	Normalize
X-4130 Steel	0.188 1.500	.022 .065	5	3	#5	#6				Torch	As Required
	1.625 2.750	.049 .120	5	3		#6				Torch	As Required
Corrosion - Resistant Steel	Minimum Bend Radius depends on Composition, Condition, and Bending Equipment.								#2		Anneal

LEGEND—METHODS OF BENDING

#1 Cold Bending (hand)
#2 Cold Bending with machine (using filler)
#3 Cold Bending with machine (internal mandrel)
#4 Cold Bending with die press (with or without filler)
#5 Cold Bending with rolls (with or without filler)
#6 Hot Bending (hand)

Figure 8—41.—Bend radii of aircraft alloy tubing.

When an airplane is designed, these lines are laid out full scale and to very close tolerances on the floor of the MOLD LOFT. Mold loft is a term that was used by shipbuilders long before the invention of airplanes. It gets its name from the fact that the space designated by a shipyard for this full-scale layout work has usually been the top floor of the largest building available where the LOFTSMAN could work in a good light and comparative quiet. On these full-scale layouts, curves can be checked for smoothness, dimensions can be checked for accuracy, and other dimensions can be determined. Templates are then made to be used in the shop fabrication of the parts.

Constructing Faired Curves

In general, a curve is considered SMOOTH OF FAIRED if a draftsman using a normally straight spline with ducks can make it lie on all points of the curve without forcing it. If any of the ducks, except one at an end, is lifted, the spline should not spring away from its position. That is, the curve should be perfectly smooth with no slight reverse curves in it.

Figure 8–42 illustrates a method of constructing a faired curve geometrically when only three points on the curve are known:

1. Locate the points for clearance, shown as A, O, and B in figure 8–42.
2. Draw a base line through point A, a line through point A which is perpendicular to the base line, and a line through point B which is parallel to the base line, thus locating point C. (See fig. 8–42A.)
3. Draw lines AD and BE through point O. (See fig. 8–42A.)
4. Draw AF so that it crosses BE at any point above O, as shown in figure 8–42B.
5. Through the intersection of AF and BE, draw line CG. (See fig. 8–42B.)

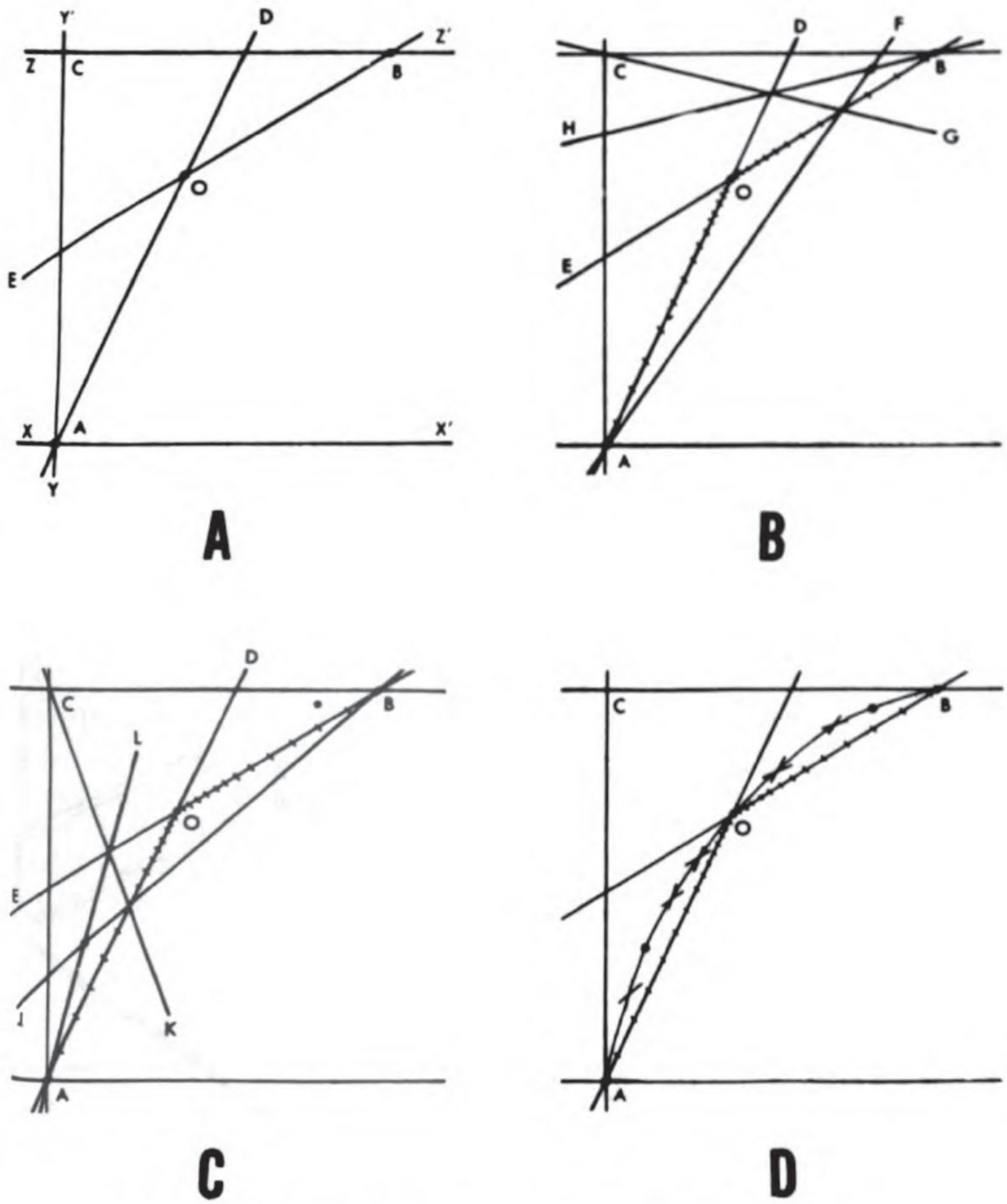


Figure 8–42.—Layout for a faired curve through a set of points.

6. Draw line BH through the intersection of AD and CG. The intersection of this line BH with AF is a point on the curve, as shown in figure 8–42B.
7. Continue this procedure, as shown in figures 8–42C and 8–42D, until as many points on the curve as are desired have been located.

Templates

Aircraft sheet metal parts are ordinarily made by scribing and cutting around templates and even the forming is done according to instruction on templates made from the drawings. These templates are usually made of sheet steel. The templates illustrated in figure 8–43 are typical and show the required standard notes and markings. To the right of the templates in the figure are the finished parts after they have been cut out and bent. At some time you may be required to work on templates. If you will study *Blueprint Reading*, NavPers 10077, you will get a more detailed description of sheet metal layout work than it is possible to give here.

Duplication of Pattern

Figure 8–44 illustrates a method often used in the shop for duplicating a sheet metal part when blueprints are not avail-

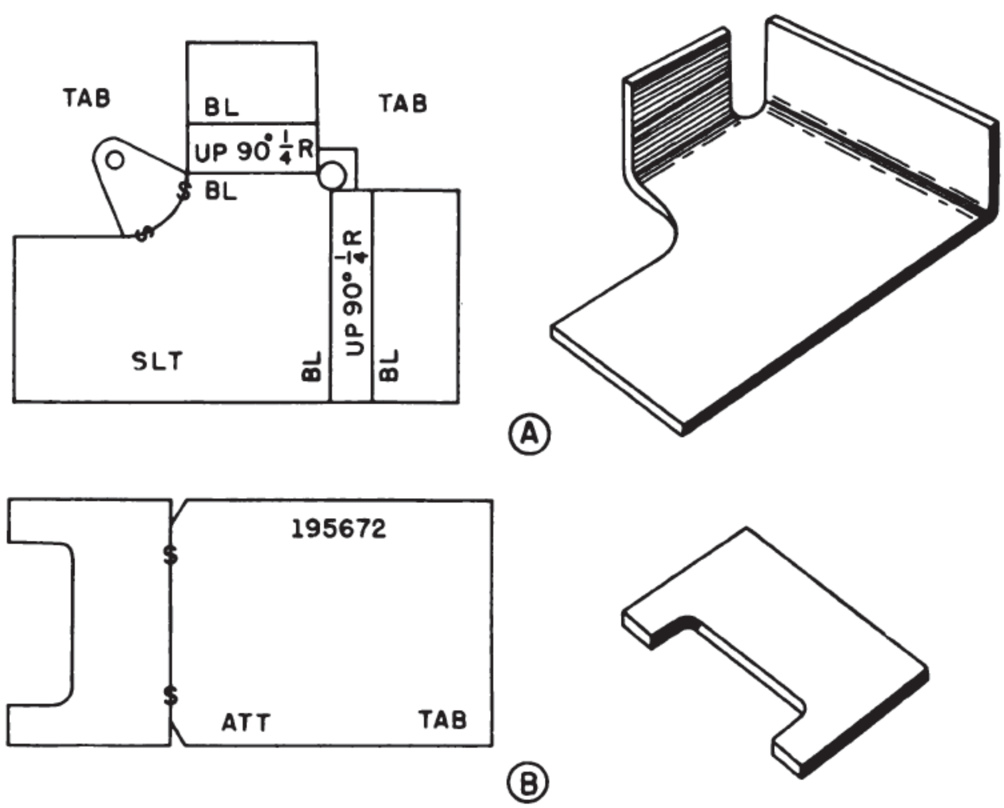


Figure 8–43.—A. Template with two tabs. B. Template with large tab.

able. The method is given here because you may also find it useful in the drawing room.

First, draw a reference line, such as AB, on the sample part and also on the drawing paper or template material. Next, draw arcs of sufficient number and sufficient length to cover the entire pattern. Increase the number of arcs where there are sharp curves on the object. An arc must pass through each corner. Then, using the intersections of arcs and reference line as centers, locate the points which give the outline of the object.

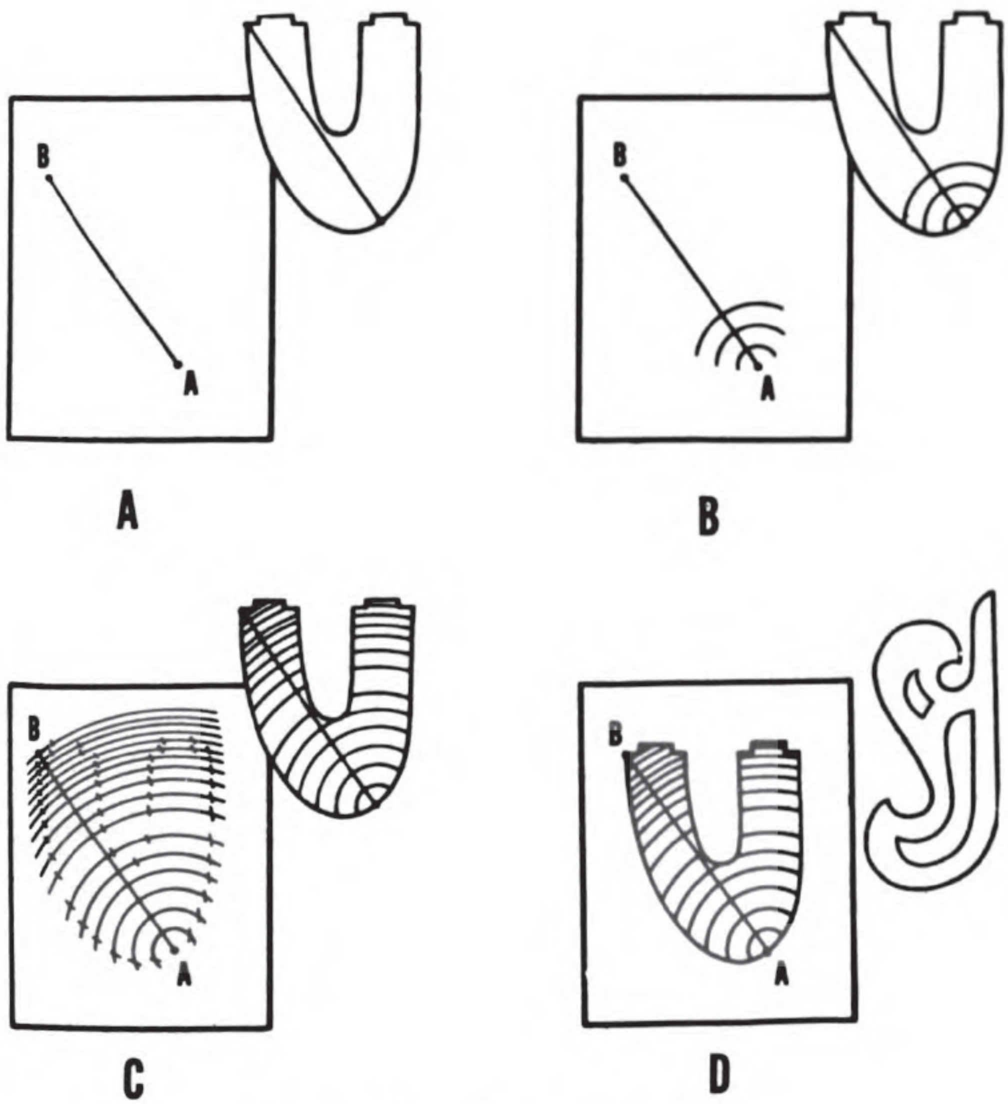


Figure 8–44.—Duplication of pattern.

QUIZ

1. What is the maximum desirable length of an aircraft drawing?
2. Give two uses of dash numbers.
3. What determines the location of station zero in a system of station marking?
4. Name three types of equipment which can often be shown more clearly in isometric or other pictorial views.
5. Why is it customary to have all dimensions read from the bottom on aircraft drawings?
6. What are the two basic types of construction used in aircraft?
7. What type of construction is used in most military aircraft?
8. What effect does the lowering of wing flaps have on the lift and the drag of the wings?
9. Give three reasons why aluminum and its alloys are widely used in aircraft manufacture.
10. What is meant by minimum radius of bend?
11. Name five types of solid shank rivet heads now used in aircraft construction.
12. When a rivet is selected, what largely determines its diameter?
13. Name four kinds of rivets that can be clinched from the side from which they were inserted.
14. What is the general rule for spacing of rivets in repair work?
15. How are bolts used?
16. In what two general groups can nuts be classified?
17. How do screws differ from bolts?
18. Name three ways in which cowling fasteners may be used.

19 When are flexible plumbing lines generally used?

20. Why are bends always necessary in any line of tubing?
21. When a bend in a tube is too sharp what may happen?
22. What is a faired curve?
23. Are sheet metal parts usually made by taking information directly from the drawing or blueprint?

CHAPTER 9

ELECTRICAL AND ELECTRONIC DRAWINGS

ELECTRICAL THEORY

Most electrical drawings are schematics or diagrams. They tell you not how an electrical system appears, but what it does and how it does it. The devices in the system are shown by standard symbols, and to know what the symbols stand for is useless, unless you also know how the devices affect electrical current or voltage. In order to understand this, you need a background of knowledge of electrical theory.

Chapter 11 of *Draftsman 3*, NavPers 10471, includes short discussions on electricity and electromagnetism. You should also read the basic Navy training courses, *Electricity*, NavPers 10622–B, and *Basic Electronics*, NavPers 10087. The quiz has been omitted at the end of this chapter because the text includes a considerable number of questions, the answers to which may be found by reference to these basic courses. MIL–STD–15A, *Electrical and Electronic Symbols*, contains the latest military standards for the symbols.

Some of you have been working as electrical draftsmen and are up to date on the basic theory. For you, the following summary may be old stuff, but check yourself on your understanding of electricity by seeing how many of the questions in this section you can answer. Some of you have only read the basic text, and electrical theory like most theory is quickly forgotten unless you have occasion to apply it. You will want to go back and read the first five chapters in NavPers 10622–B carefully before you answer the following questions:

1. How do like charges of electricity act on each other?
2. How do unlike charges act on each other?
3. How does a capacitor (condenser) act to store electrical energy?
4. What is the unit of measure of current strength?
5. What two things control the strength of current in a circuit?
6. What four things affect the resistance of a conductor?
7. Why are fuses made of metals which melt at a relatively low temperature?
8. Why are no intentional grounds used on regular Navy ships?
9. What does emf mean?
10. What four kinds of energy can be converted into electrical energy?
11. What are the two most common sources of electrical power?
12. Why can't primary cells be recharged?
13. What is the principal advantage of secondary cells?

Ohm's Law

Next read Chapter 6 in *Electricity*. An understanding of Ohm's law, which is discussed in this chapter, is fundamental to an understanding of the electrical circuits which you must draw, because it defines the relationship between current, voltage, and resistance. In any electrical circuit, if the voltage is held constant and the resistance is increased, the current DECREASES in proportion to the INCREASE in resistance. If the voltage is held constant and the resistance decreased, the current INCREASES in proportion to the DECREASE in resistance.

The chapter ends with three statements which anyone working with circuits must keep constantly in mind:

1. The strength of the electrical current, or amperage, depends on both the resistance of the circuit and the voltage applied to the circuit.

2. The resistance does not depend on either the current or the voltage. The character of the conducting path, the wires and the load, determine the resistance.
3. The emf of a circuit does not depend on either current or resistance, but is determined entirely by the generator or battery supplying the circuit.

Electromagnetism

Chapter 11 of *Electricity* discusses another power, magnetism, and chapter 12 introduces you to electromagnetism. Few electrical machines or devices are operated by electricity alone. Their action usually comes from the interaction of the two forces—electricity and magnetism. In chapter 13, this interaction, induction, is discussed.

Be sure that you can answer the following questions on the material in these chapters:

1. What is the name given to the arrow which is used to show the direction and strength of a force?
2. How do like magnetic poles act toward each other?
3. How can you increase a coil's strength without changing the construction?
4. What two factors control the direction of an induced emf?
5. What three factors control the strength of an induced emf?
6. How many circuits are necessary for mutual induction?
7. How many circuits are necessary to produce self-induction?
8. Will steady direct current produce a continuous self-induction? Why?
9. In what way does pulsating d-c differ from regular d-c?
10. In what two ways does a-c differ from regular d-c?

Chapter 17 in *Electricity* discusses a-c circuits. Be sure you know how resistance, inductive reactance, and capacitive reactance affect the phase of an alternating current. Remember that an induced voltage is always opposed to the change in current that is producing it. If the current is increasing, the induced emf opposes the increase and has an opposite polarity to that of the current. If the current is decreasing, the induced emf opposes the decrease and has the same polarity as that of the current. This effect of self-inductance is greatly increased if the conductor is wound into a coil, and it is increased still more if the winding is on an iron core. Self-inductance has the effect of causing the current to lag behind the applied voltage.

Capacitance is the ability or tendency of certain parts of a circuit to absorb and hold an electric charge for a short period of time. The effect of capacitive emf in an a-c circuit is to cause the current to lead the applied voltage. The capacitive emf in a circuit always opposes the inductive emf that exists in the circuit. Capacitance causes the current to lead the applied voltage, whereas inductance causes it to lag. Thus inductance and capacitance produce opposing effects.

The ratio of the induced voltage to the current is called inductive reactance. Similarly, the ratio of the capacitive emf to the current is called capacitive reactance. Individually, inductive reactance and capacitive reactance both limit the flow of current. Collectively they cancel each other and the net reactance is equal to their difference.

Almost every kind of electrical device produces either one or the other of these effects on the a-c circuit. A-c induction motors have a high inductive effect. Synchronous motors, on the other hand, have a high capacitive effect under certain conditions. Long distance telephone lines have high capacitance. Sometimes a capacitor or an induction coil must be inserted in a circuit to bring the X_C (capacitive reactance) and the X_L (inductive reactance) into proper balance.

The design of a shipboard power distribution system varies with a vessel's function. A-c systems are installed in battleships, carriers, cruisers, destroyers, escort vessels, and numerous auxiliary vessels. D-c systems are installed in submarines, small surface vessels, and large auxiliary vessels with considerable deck machinery that requires d-c service for its operation.

In general, d-c motors are used where wide variations of speed are required, as on winches, windlasses, and the steering gear of ships. Direct current must be used, for example, to charge storage batteries, and the current from a storage battery cannot be used in a system built for a-c, so d-c is used in any electrical system where a reserve supply of energy must be carried in storage batteries.

One of the most desirable features of the alternating current system is the ability to change its voltage efficiently with transformers. A-c generators (alternators) and motors are usually of simpler mechanical construction than d-c generators and motors, and usually give longer service between overhauls.

Generators and Alternators

Chapter 14 of *Electricity* discusses d-c generators and a-c alternators. The principles involved in these machines can be applied to motors and to many electrical devices which act in the same way. Chapter 21, "Electrical Machines," gives a résumé of these principles. Be sure that you can answer the following questions:

1. What is the name of the iron frame on which the pole pieces of a generator are mounted?
2. What is the movable core of the generator called?
3. What type of current is produced by the moving coils of a generator?
4. What is the name of that part of a generator which converts the current produced in the coils to direct current?

5. How are the majority of alternators mechanically opposite in design to generators?
6. What is the part of an alternator which carries the rotating field poles?
7. What is the frame of an alternator called?

Motors

If a closed coil is forced to rotate through a magnetic field, an induced current is produced in this coil and mechanical energy is converted into electrical energy. That is generator action. When current flows through a conductor and the conductor is in a magnetic field, a force acts on the conductor which tends to move it out of the field, and electrical energy is converted into mechanical energy. That is motor action.

Like the generator, the d-c motor includes a stationary iron yoke or frame on which the pole pieces are mounted, a rotating armature, and a commutator. In a motor, the torque, or turning effort, must always be unidirectional if the armature is to rotate. This is accomplished by reversing the current in the armature coils at the instant they pass from one pole to the next; that is, by converting the direct current in the external circuit into alternating current in the armature circuit. The commutator of a d-c motor converts the direct current into alternating current by automatically reversing the connections between the armature coils and the external circuit each time a coil passes through the commutating zone.

Because it does not use a commutator, the a-c induction motor is not subject to many of the troubles encountered in the operation of d-c machines, such as sparking, high segments, bad brushes, and shorted segments. Its design is simple and its construction rugged. It is particularly well adapted to constant-speed variable-torque loads, but it is possible to adapt the motor to some variable-speed loads. However, because of the additional features required for variable speeds, induction motors for this type of service are

expensive and generally inefficient compared with variable-speed d-c motors.

The answers to the following questions concerning motors may be found in Chapters 15 and 16 of the *Electricity* course. If you find you have difficulty answering any of them, review these chapters.

1. How does a d-c motor differ from a d-c generator in construction?
2. How is a compass needle reacting in a magnetic field like a tiny motor?
3. What is torque?
4. What happens to the amount of counter-emf if a d-c motor is slowed?
5. Why is a rheostat used on large motors?
6. Do a-c coils have a fixed polarity?
7. What does "polyphase" mean?
8. What is another way of saying "$\frac{1}{240}$ of a second out-of-phase?"
9. What is a magnetic lock?
10. Why are single-phase motors less efficient than three-phase motors?
11. Describe a centrifugal switch on a motor?
12. How do solenoid coils act as motor overload relays to stop the motor when it begins drawing too much current?

Transformers

Mutual induction occurs whenever the lines of flux of a magnetic field around a coil are cut by another coil. If a constant direct current is flowing in the primary coil, the secondary coil must move if it is to cut through the magnetic field, as in a d-c generator or motor. However, if the current in the coil in the primary circuit is a pulsating direct current, or alternating current, both coils may remain stationary. A transformer consists basically of two stationary coils, and it is used in an a-c circuit not to increase power but to change the ratio between voltage and current.

It is transformers and their use in a-c circuits that make alternating current better than direct current for use where power is to be transferred over long distances. For example, suppose an alternator has an output equal to 230 volts and 40 amperes. This current enters a transformer which steps up the 230 volts to 2,300 volts. This is a stepup ratio of 1 to 10. However, transformers do not increase power. They simply change the ratio between voltage and current. Therefore when voltage is stepped up, current is cut down. In this case, the current would decrease from 40 amperes to 4 amperes. With this low current in the circuit, smaller wires can be used, and there is less heat loss. At the equipment end, a transformer can again be used to alter the ratio between current and voltage, stepping the voltage down to 230 volts and the current up to 40 amperes, or to some other ratio at which the equipment will function efficiently.

The amount of stepup or stepdown in voltage depends on the number of turns in the primary coil compared to the number of turns in the secondary coil. For example, if the size of wire used in both coils is the same and the primary main voltage is 220 volts, you would use a transformer whose secondary coil has half as many turns as the primary if you want a secondary voltage of 110 volts.

1. How is energy transformed from the primary to the secondary of a transformer?
2. Suppose d-c were fed into the primary of a transformer, what would happen?
3. Explain how the secondary current controls the amount of primary current.
4. If a welding transformer has a 1-turn secondary that delivers 400 amperes and an 800-turn primary, what is the primary current?
5. Is it absolutely correct to say that transformers are 100 percent efficient?
6. What are the two kinds of losses that occur in a transformer?
7. How can the losses of a transformer be reduced?

Electron Tubes

One of the basic components of any electronic equipment is the electron tube. The electron tube consists of a glass or metal shell which encloses a cathode, a plate, and usually one or more grids. The shell of the tube may be evacuated, in which case, it is a vacuum tube, or it may be filled with gas.

Electron tubes and their action in radio circuits are discussed in Chapter 19 of *Electricity*. Test yourself on your knowledge concerning them by answering the following questions:

1. In thermionic emission, why do electrons shoot off the metal surface?
2. Why is the air removed from a vacuum tube?
3. Why is the cathode negative regardless of battery connections?
4. Why does current never flow from plate to cathode?
5. How does a diode act as a rectifier?
6. How does a grid control current in a triode?
7. Why must the grid be biased negatively?
8. How does a triode amplify signals?

CHAPTER 10

DRAWINGS, SPECIFICATIONS, AND TAKEOFFS FOR STRUCTURES

BUREAU OF YARDS AND DOCKS DRAWINGS

The design, construction, alteration, repair, and improvement of Navy shore-base facilities are under the supervision and management of the Bureau of Yards and Docks. Except at advanced bases, where erection is done by construction battalions, most construction is done by contract. A proposal for a construction project ordinarily takes the form of a schematic, which must be reviewed and approved by the management bureau and an officer authorized by the Bureau of Yards and Docks, before any work is done on the design and construction.

When the project is approved, a drawing number is assigned and complete working drawings and specifications are prepared. Invitations for bids from contractors are then made by advertising or other methods that provide open and fair competition. The contract is awarded to the bidder whose bid is considered most advantageous to the Government when price and other factors are considered. Drawings and specifications, which form the basis of contractual relations, are very carefully checked to eliminate anything that might cause a misunderstanding.

Upon completion of a project, the Bureau requires that any modifications of the original design be shown or indicated on the original drawings. These drawings then show actual finished conditions and are known as record drawings.

In addition to the Joint Army-Navy and Military Stand-

ards, the sizes and format of BuDocks drawings must conform to current Bureau instructions. The technical publication, TP–Te–1, *Surveys, Drawings, and Specifications*, published by the Bureau, contains regulations of the Bureau concerning both drawings and specifications.

Although pencil drawings on paper are generally acceptable, ink tracings on linen are used where very clear or very frequent reproduction is required. Where pencil drawings are made, it is recommended that transparencies be made and these used for reproduction in place of the originals.

Each drawing sheet must bear a BuDocks serial number, a sheet designation number, the number of sheets in the contract set, the number of the corresponding specification, and the contract number, if any. Notes and statements on the drawing sheets should refer only to design and construction. Statements as to the quality of materials, workmanship, inspections, tests, guarantees, etc., should be included in the specifications only.

The drawing in figure 10–1 was prepared by the Bureau of Yards and Docks especially for use in this training course. Note that all the plans, elevations, and details for a one-bedroom house, plus the legend, architectural symbols, plumbing symbols, and electrical symbols, in addition to work schedules, are included.

The scales are given at the bottom of the sheet, both as equations and as graphic scales. The plans and elevations were drawn to a scale of $\frac{1}{4}'' = 1'\text{-}0''$ and the sections to a scale of $\frac{3}{4}'' = 1'\text{-}0''$. It is convenient to speak of the scales as equations, but when the drawing is reduced from its original size, the equations are no longer valid for scaling purposes. However, scaling of the drawing can still be accomplished by using the graphic scales.

No effort has been made to place the plans and elevations in third-angle orthographic projection, but they have been

grouped so that their relationship to each other can easily be seen. The floor plan shows the materials and construction of the walls. The foundation and floor framing plan below it indicates materials and construction of the foundation and floor. Below that are two truss drawings, one for wooden rafters and the other for steel.

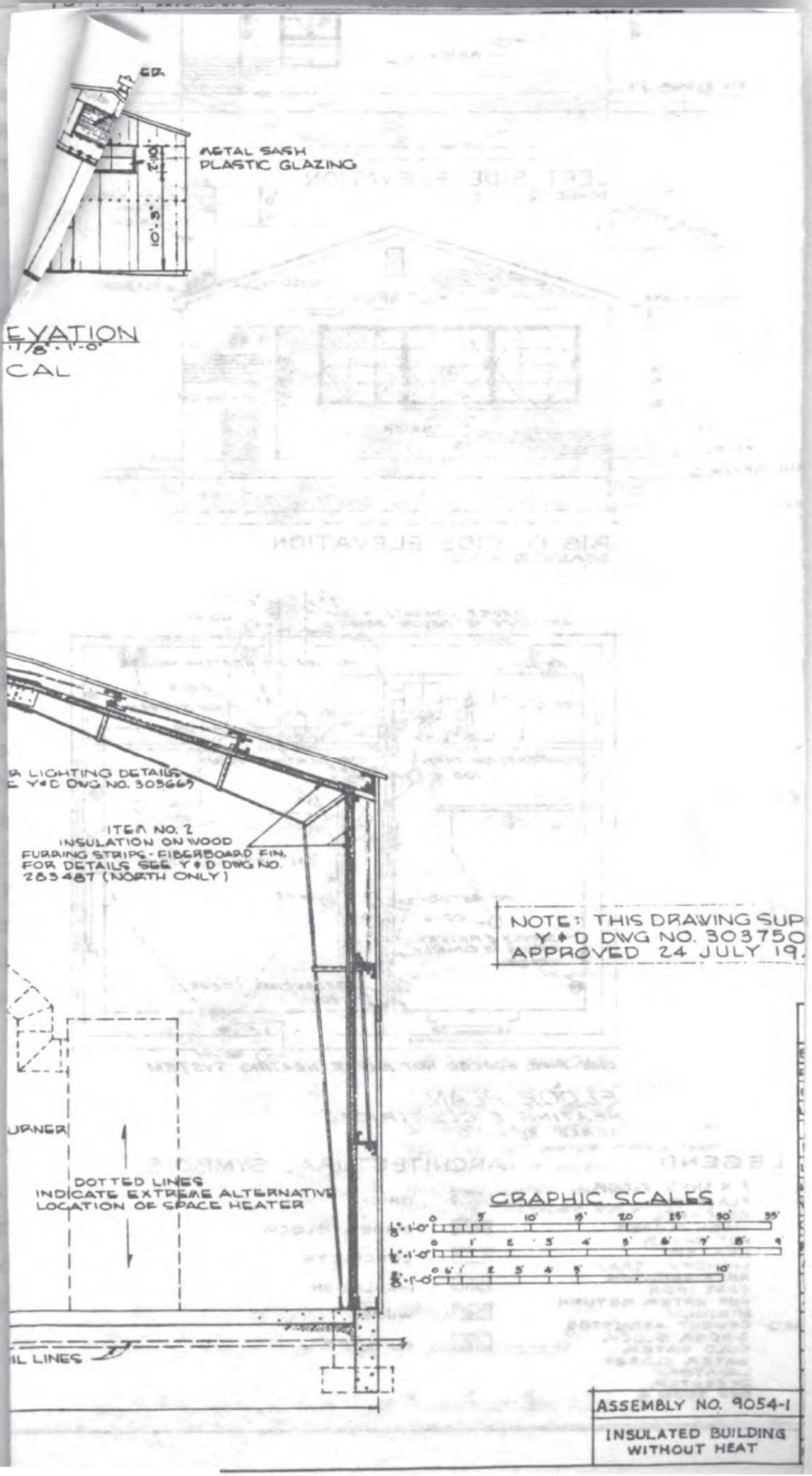
The heating and electrical systems are shown on one plan and the plumbing on another. The three sectional drawings are actually the same section, but one indicates the construction details when masonry is used, the second when the construction is wood frame, and the third when it is steel frame.

The specifications to accompany this drawing are discussed in a later section of this chapter.

Advanced Base Drawings

The Bureau of Yards and Docks has prepared standard drawings to cover all major installations or structures that might be needed at an advanced base. These are compiled in a book called *Advanced Base Drawings*, NavDocks P–140. The drawings are done in a somewhat schematic manner to provide field personnel with necessary basic information. The Bureau recognizes the fact that many installations will require deviation from the plans in order to meet specific field conditions. Most of the items of material required for any assembly are identified in the bill of material by standard Navy stock numbers. Some of the older drawings have items identified by the now obsolete Yards and Docks stock list numbers.

The standard Navy stock number is the official identification number of any item of Navy material, whether the number is used in the catalog, on a stock bin tag, on a requisition, or on a drawing. Each number has four principal parts, as illustrated in figure 10–3. Practically all the stock numbers found in the bills of material of NavDocks P–140



METAL SASH
PLASTIC GLAZING
EVATION
CAL
LEFT SIDE ELEVATION
RIGHT SIDE ELEVATION
LIGHTING DETAILS
Y+D DWG NO. 303663
ITEM NO. 2
INSULATION ON WOOD
FURRING STRIPS - FIBERBOARD FIN.
FOR DETAILS SEE Y+D DWG NO.
283487 (NORTH ONLY)
NOTE: THIS DRAWING SUP
Y+D DWG NO. 303750
APPROVED 24 JULY 19
URNER
DOTTED LINES
INDICATE EXTREME ALTERNATIVE
LOCATION OF SPACE HEATER
GRAPHIC SCALES
IL LINES
ASSEMBLY NO. 9054-1
INSULATED BUILDING
WITHOUT HEAT

11	SCREW, MACH, RH, 1/4 - 20	EA	G45-S-15692	–	12
12	PIPE, STEEL, STD, T & C, 1/2"	LF	G44-P-1178	–	273
13	BUSHING, IRON, STD, 1/2" x 1/4"	EA	G45-B-2629	–	6
14	BUSHING, IRON, STD, 1/2" x 3/8"	EA	G45-B-2630	–	6
15	ELBOW, MI, 90°, 1/2"	EA	G45-E-8479	–	17
16	NIPPLE, STEEL, STD, 1/4"	EA	G45-N-2047	–	6
17	NIPPLE, STEEL, STD, 3/8"	EA	G45-N-2048	–	6
18	NIPPLE, STEEL, STD, 1/2"	EA	G45-N-2049	–	6
19	NIPPLE, STEEL, STD, 1"	EA	G45-N-2051	–	2
20	TEE, MI, SCR, STD, 1/2"	EA	G45-T-7753	–	3
21	UNION, GJ, MI, STD, 1/2"	EA	G45-U-1156-15	–	6
22	VALVE, GATE, 1/2"	EA	G45-V-7512	–	3
23	SOLDER, BAR, 50/50	LB	G46-S-800	–	4
24	FLUX, TIN-LEAD	CAN	G51-F-660	–	3
25	CAP, FLUE SHEET METAL, FOR 10" DIA FLUE PIPE	EA	Y54-C-38-70	–	2
26	FLASHING, FLUE, FOR 10" DIA FLUE PIPE COMPLETE WITH COUNTER FLASHING, COLLAR, INNER SLEEVE AND INSECT SCREEN	EA	Y59-F-377-86	–	2
27	TANK, STEEL, 25 BBL	EA	C59-T-13900	–	1
28	HEATER, SPACE, OIL FIRED, 200,000 BTU; COMPLETE WITH CONTROLS, ACCESSORIES, 20 FT OF 10" FLUE PIPE, 1-90° & 2-45° ELBOWS (FLUE CAP & FLASHING NOT INCLUDED)	EA	C66-H-351	–	2
29	TAPE, FRICTION, 3/4"	RL	G17-T-805	–	1
30	TAPE, RUBBER, 3/4"	RL	G17-T-1445	–	1
31	EXTINGUISHER, FIRE, FOAM, 2 1/2 GAL	EA	G58-E-212	–	1

NOTES

1. BUILDING AND FOUNDATION DETAILS AND DIMENSIONS SHALL BE CHECKED IN FIELD WITH MFGRS PACKAGED BUILDING DWGS

ERSEDES
45

REFERENCE DRAWINGS

BUREAU OF Y & D NOS
FOUNDATION: 548251
INSULATION: 283487
LIGHTING: 303665

IF REQUIRED:
LEAN-TO: 264099
HOTAIR LEAN-TO: 484990
WATER PIPING: 264257
COMPRESSED AIR: 303772
RECEPTACLE CIR: 303664
100 AMP BUS: 504150
200 AMP BUS: 504151
400 AMP BUS: 504152

ASSEMBLY NOS
TROP 1054
NORTH 9054

FUNCTIONAL COMPONENT

SYMBOL	DESCRIPTION	DATE	APPROVAL

REVISIONS

DEPARTMENT OF THE NAVY — WASHINGTON, D.C.

BUREAU OF YARDS & DOCKS

	ARCH	MECH	ELEC
DRWN	WILSON	FCH	WILSON
TR	WILSON	WILSON	WILSON
CHK	LEWIS	[illegible]	[illegible]
LDR	LEWIS	FCH	[illegible]
SUPV	[illegible]	[illegible]	[illegible]
HEAD	[illegible]	[illegible]	[illegible]
MGR	[illegible]		

PROJ MGMT [illegible]
DIRECTOR [illegible]

ADVANCED BASES
STANDARD 40' x 100'
STEEL RIGID FRAME BLDG
ARCH MECH ELEC

APPROVED Martin W Kehart
FOR CHIEF OF BUREAU
DATE 7/31/62

SATISFACTORY TO ______

DATE ______ BY ______

SCALE AS NOTED | W R NO. 50,159
SHEET 1 OF 1
Y & D DRAWING NO. 303750

Figure 10–2

Cognizance symbol → GF 53–P–2965
Fraction code
Class designator
Group designator
Stem number

Figure 10–3.—Parts of a Navy stock number.

begin with either G, Y, or C. G indicates that the particular article is listed in the General Stores Section of the *Catalog of Navy Material*. Y's and C's indicate that an article is listed in the Yards and Docks Section.

If the assembly covered by a certain drawing is to be used as a part of other assemblies, it is given an assembly number. This assembly can then be listed as a single item in the bill of material for other assemblies and identified by its assembly number. For example, in the bill of material for the steel rigid-frame building in figure 10–2, the glass fiber insulation and the foundation and floor slab are identified by the assembly numbers 1411–2 and 1891. Details of these two items will be found on other sheets, the numbers of which are given in the block under the heading REFERENCE DRAWINGS. The building, complete with the basic electrical and mechanical equipment, is likewise identified by its assembly number in the bills of material for shops, storage buildings, and numerous other installations. The assembly number used will be one of the three indicated at the bottom of the sheet, depending on whether the assembly is for tropical or northern use or for some installation where insulation is required but oil-fired heaters are not.

SPECIFICATIONS

Architectural specifications contain in writing information on materials, construction methods, tests, etc., which is impractical to put in the drawings. To the contractor and the foreman on the construction job, they are as important as the

drawings, and they are studied and referred to constantly. Construction contracts are based largely on the requirements laid down in the specifications. For these reasons, they must be very carefully prepared, giving all necessary information, and yet, they must be brief and concise, permitting only one interpretation. The following points will help you to prepare concise, accurate, and complete specifications:

1. Use simple words.
2. Use technical terms in their exact meaning.
3. Use pronouns only if it is clear to which noun they refer.
4. Avoid long sentences.
5. Be careful in the use of punctuation.
6. Give directions and not merely suggestions.
7. Specify desired results rather than the methods to be used.
8. Use a checklist to avoid repetition, contradiction, and illogical arrangement.

The Bureau of Yards and Docks has prepared NavDocks Form No. 129h, for use when manuscripts of specifications are prepared. The use of the form is discussed in TP–Ad–4, *Contract Administration.* The Bureau has also published a *List of Specifications Used in Contracts for Public Works*, NavDocks P–34, which includes Bureau specifications which are to be used as manuscripts and not referenced and those which may be referenced, as well as pertinent Navy, military, and Federal specifications.

The following specifications for a single house with one bedroom were prepared by the Bureau of Yards and Docks to accompany Yards and Docks Drawing No. 46582, which appears as figure 10–1. Read these specifications in reference to the figure.

DEPARTMENT OF THE NAVY
BUREAU OF
YARDS AND DOCKS

NAVDOCKS
SPECIFICATION
NO. 00001

NAVY TRAINING PUBLICATIONS CENTER

Illustration for Draftsman

SPECIFICATION
FOR
SINGLE HOUSE—ONE BEDROOM

CONTENTS

SECTION 1. GENERAL CLAUSES.

1–01. General description.—The building will be one story with a crawl space, and will be supported on concrete or masonry foundations. The construction will be by one of the following methods:

(a) Masonry exterior walls, with wood framed floor, partition, and roof construction.

(b) Wood frame exterior walls, interior partitions, and floor and roof construction.

(c) Light steel frame exterior walls and trussed roof rafters, with steel bar joists and concrete slab for the floor construction, and with wood frame interior partitions.

(d) Any other combination of the methods and materials of construction mentioned hereinbefore. Windows will be of metal of the casement type, or of wood of the double-hung type. Doors will be of wood. Insect screens and screen doors will be provided. On buildings having wood frame or light steel frame exterior walls, the exterior wall finish will be cement-asbestos shingles applied on wood sheathing. Roofing will be asphalt shingles applied on wood sheathing. Thermal insulation will be provided in the roof space. Interior walls, ceilings, and partitions will have plastered finish. Wood finish flooring over wood subflooring will be applied on wood framed floor construction. Asphalt tile will be applied to concrete floor slab where steel bar joists are used. Bathroom will have tiled floor, and a tiled wainscot around the tub only. Kitchen will have asphalt tile floor covering applied on wood flooring. Heater room will have concrete floor slab, and cement-mortar plastering on wood framed walls, partitions, and ceiling, applied on metal lath. Complete heating, plumbing, and electrical systems will be provided, including the fixtures. The following work is not included as a part of this specification:

(1) Electric refrigerator;

(2) Electric or gas range;

(3) Window shades and venetian blinds;

(4) Clothes washing and drying units (automatic type):

(5) Garbage disposal unit;

(6) Sidewalks;

(7) Rough and fine grading around the exterior of the building; seeding or sodding;

(8) Extension of utilities beyond a point 5 feet outside the foundation walls of the building.

1–02. Definition.—As used herein, "provide," or "provided," shall be understood to mean "provide complete in place," that is, "furnish and install."

1–03. Drawing accompanying specification.—Drawing number 465682, dated 21 September 1953, accompanies this specification, and is a part thereof.

SECTION 2. EARTHWORK.

2–01. General requirements.—Excavations shall be carried to the dimensions and depths indicated or necessary. Excavations carried below the depths indicated, without specific directions, shall be refilled to the proper grade with thoroughly compacted suitable fill, except that in excavations for wall, pier, or other footings, the concrete shall be extended to the bottom of the excavation; all additional work of this nature shall be at the contractor's expense. Crawl spaces shall be excavated and graded to a uniform level not less than 2 feet below the bottom of the first story framing. Trenches for pipe lines shall be excavated along straight lines, and unless indicated otherwise, shall have a minimum of 6 inches between the outside of the pipe bell and the side of the trench or bracing, with a minimum width of trench of 2 feet; additional excavation shall be made under bell ends to allow for calking and to give the pipe a uniform bearing. Excavations shall be kept free from water while construction therein is in progress. Backfill shall be placed as far as practicable, as the work progresses, in not more than 6-inch layers, and compacted to the maximum density practicable. The moisture content of the fill material shall be such that proper compaction will be obtained. Grading around the building to a point 5 feet outside the foundation walls shall be finished reasonably smooth and sloped to drain away from the building in all directions; all material used for filling, backfilling, and grading shall be clean earth.

2–02. Topsoil.—Material from excavations suitable for topsoil shall be deposited in piles separate from other excavated material. Piles of topsoil shall be located so that the material can be readily used for finished surface grading and shall be protected and maintained until needed. Topsoil, when used for finished surface grading, shall be spread uniformly to a point 5 feet beyond the foundation walls of the building, and rolled lightly to a thickness of about 4 inches.

2–03. Disposition of surplus material.—Surplus material, not required for filling, backfilling, or grading, shall be deposited at the site of the work, and graded in such manner that the existing surface drainage will be maintained.

SECTION 3. CONCRETE

3–01. General requirements.—All concrete shall be proportioned by volumetric measurements, using 1 part cement to 2 parts of sand and 4 parts of gravel or crushed stone. Cement shall be approved brand

of standard portland cement. Water for mixing concrete shall be potable. Sand, gravel, or crushed stone shall be of approved grades, clean and free from salt, dirt, clay, alkali, organic matter, and other impurities. Coarse aggregate shall be of a size that will be retained on a ¼-inch screen and will pass a 1-inch screen. Not less than 5 sacks of cement, and not more than 7 gallons of water per sack of cement shall be used for each cubic yard of concrete. Concrete shall be mixed thoroughly to a uniform color and consistency, and shall be placed within 30 minutes of the time of mixing; retempering will not be permitted. Concrete as deposited shall be thoroughly tamped, spaded, rodded, or worked as the case requires; where concrete is in contact with the earth, the earth shall be dampened before the concrete is placed.

3–02. Finishes.—Concrete platforms at front and rear doors shall be poured on well compacted earth subgrades; the exposed top surfaces of platforms shall be troweled hard and smooth, and shall be sloped slightly to drain away from the building. Cleavage joints consisting of several thicknesses of heavy saturated felt shall be provided between concrete slabs and vertical masonry surfaces. Sills at front and rear doors shall be of precast or poured-in-place concrete.

3–03. Concrete slabs.—Where concrete floor slabs are indicated to be used over steel bar joist construction, the concrete shall have a thickness of not less than 2 inches. The concrete shall be poured on waterproofed-paper-backed, welded, zinc-coated steel wire fabric forming that is clipped and secured to the top members of the joists; welded fabrics shall be 3- by 4-inch mesh having diameter of wire of not less than 0.0155 inch. The coarse aggregate shall be as specified hereinbefore except that it shall be of such size as will pass a ½-inch screen; the concrete mix shall be 1 part cement, 2½ parts fine aggregate, and not more than 3½ parts coarse aggregate. The slab shall be screened and troweled to a uniformly level and smooth surface suitable for the application of asphalt tile, and at the proper elevation. Concrete floor slabs in the heater room adjoining the kitchen shall be of construction similar to the above.

SECTION 4. MASONRY

4–01. General requirements.—Foundation walls from footings to the finished grade shall be constructed of concrete masonry units. At the option of the contractor, he may substitute poured-in-place concrete foundation walls having a thickness of not less than 8 inches for the concrete masonry unit walls. Exterior walls of the building shall be constructed of concrete masonry units, faced on the exterior with common brick. Chimney shall be constructed of common brick with a fire clay flue lining, and with a precast concrete coping at the top.

4–02. MATERIALS.

(a) BRICK shall be selected hard-burned common clay brick of standard dimensions, having true faces, and straight and sharp edges and corners, and having an absorption of not more than 15 percent by weight.

(b) CONCRETE MASONRY UNITS shall be the lead-bearing type of standard dimensions and may be formed of concrete, cinder concrete, or slag; they shall have a face shell thickness of not less than 1¼ inches and shall have a maximum water absorption of 15 pounds per cubic foot (average of 5 units), when tested in accordance with specification ASTM C90–52. Concrete units may be air-, water-, or steam-cured; air-cured units shall be held in storage after manufacture a minimum of 28 days; steam- or water-cured units shall be held in storage after manufacture a minimum of 10 days. All units shall be kept dry until used.

(c) MORTAR shall be mixed in the proportions by volume of 1 part portland cement, 1 part hydrated lime paste, and 6 parts masonry sand, or of 1 part approved masonry cement and 3 parts masonry sand. A sufficient amount of water shall be added and the mortar shall be mixed until the plasticity necessary for the purpose intended is obtained. The mortar shall be used so that it will be in place before the initial setting of the cement has taken place; retempering of mortar will not be permitted.

4–03. WORKMANSHIP.—The work shall be built level, square, plumb, and true. Brick and concrete masonry units shall be so handled that their edges and faces will not be chipped, spalled, or cracked. All brick shall be wetted thoroughly and permitted to drain surface dry before being laid in the walls, except during freezing weather. All drilling, fitting, and cutting required by other work and for making good after such work shall be done as necessary. Bolts, anchors, ties, lintels, sleeves, and any other work specified elsewhere in connection with the masonry shall, where practicable, be placed in position as the masonry work progresses. Joints in masonry work shall be not less than ⅜ inch, nor more than ½ inch, in width, and shall be level, plumb, and uniform in thickness. All brick shall be laid in common bond, with a through brick header course at every seventh course to bond with the concrete masonry unit backup; the brick facing shall be laid up first and after 6 courses are laid, the interior face of the brick wall shall be parged with a ½-inch thick coating of cement mortar, and then backed up with 2 courses of concrete masonry units to form a bed for the through header course. All brick shall be shoved up in full mortar beds and all joints shall be entirely filled

with mortar, both bed and head joints. Concrete masonry units shall be laid by the "face-shell bedding" method. When the mortar in the joints of the brickwork is firm enough, it shall be tooled slightly concave, pressing the mortar in firm contact with all edges and ends of the brick. Joints in concrete masonry unit work shall be struck flush. After the joints in brickwork have been tooled, the exposed exterior surface of the walls shall be brushed to remove all loose and excess mortar. A sample panel not less than 4 feet long and 3 feet high shall be laid up for approval before the masonry work is started showing the coursing, jointing, and bonding of the work; the finished work shall match the approved sample. Sills of windows shall be selected brick laid flat, and in a full bed of cement mortar to provide a wash and drip. Windows and door frames shall be built in as the work progresses and shall be plumbed, squared, braced, and anchored in position securely. Anchor bolts for sills and plates, and loose steel lintels for heads of doors and windows shall be built in properly. Masonry shall not be laid during freezing weather, nor when it appears probable that freezing temperatures will occur before the mortar has set, unless, subject to approval, proper precautionary measures are taken. Upon completion all masonry work shall be pointed where necessary. All exposed surfaces of common brickwork shall be washed with stiff fiber brushes and a dilute solution of muriatic acid, followed immediately by rinsing thoroughly with clean water until all traces of the acid have been removed. All work that might be damaged, stained, or discolored during the cleaning operation shall be protected in a suitable manner. All workmanship shall be of the highest grade.

4-04. FLUE LININGS AND THIMBLES shall be of hard-burned fire clay, and shall be free from fractures, large or deep cracks, blisters, and other defects. They shall be set with fine clay mortar and the interior of the flues shall be kept free from mortar droppings. Thimbles of required dimensions shall be provided for flues and shall be located where directed. Chimney caps shall be calked around edges of flue lining with elastic cement.

SECTION 5. MISCELLANEOUS STEEL AND IRON WORK.

5-01. GENERAL REQUIREMENTS.—Steel and iron shall be standard, well-finished structural shapes, or bar steel or bar iron. Cast iron shall be soft, tough gray iron. Wire not otherwise specified shall be cold-drawn steel.

5-02. ANCHORS AND BOLTS shall be provided where necessary for securing work in place. They shall be embedded in the masonry as it is constructed, and unless indicated or specified otherwise shall be installed approximately 2 feet on centers. Standard type joist an-

chors shall be provided at every third joist; anchors shall be 3/16 by 1¼ by 24-inch long steel straps spiked to the sides of joists and extending not less than 4 inches into the masonry with a hook end; joists paralleling walls shall be anchored thereto at not to exceed 8-foot spacings by 3/16 by 1¼ by 48-inch long steel straps, dapped in and spiked to the tops of at least 4 joists and embedded in the masonry at least 4 inches. Girders shall be anchored to concrete or masonry piers by means of U-shaped steel strap anchors. Pressed steel joist hangers of proper size shall be provided for framing around chimney, and at other locations as necessary.

5–03. CLEAN-OUT DOOR AND FRAME of cast iron shall be installed in the base of the chimney; door shall be about 8 by 10 inches, shall be hinged, and shall have latch or other suitable device for holding the door in a closed position. Door shall fit the frame neatly to provide as nearly an air-tight joint as practicable.

5–04. CAST IRON OR STEEL GRADE VENTS shall be provided in the foundation walls; they shall have cast iron or steel frames extending into the reveals, with provision for anchoring securely in place, and shall have square or diamond-shaped latticed fronts with about 1-inch square openings. Zinc-coated hardware cloth screens, in removable frames that can be replaced, shall be provided over the interior face of the latticed openings. Grade vents having doors to close the opening and of a type that can be operated from the exterior, may be provided. Similar type vent shall be provided in the exterior wall to the heater room.

5–05. LINTELS shall be of structural steel members; they shall be of ample length to provide at least a 6-inch bearing at each jamb. Steel bearing plates, ⅜-inch thick shall be provided for openings over 4 feet wide.

5–06. STEEL FLOOR, WALL, AND ROOF FRAMING.

(a) STEEL BAR JOISTS.—Materials, fabrication, and erection shall be in accordance with the standard specifications of the Steel Joist Institute, except as modified by the drawings or this specification. Diagonal strut bridging shall be provided, consisting of ¾-inch steel box channels welded or clipped to each joist, and anchored at the side walls into the masonry. The ends of steel joists shall have not less than 4-inch bearing on the masonry walls, and shall be provided with anchors. Extreme care shall be exercised during construction so that excessive loadings, or concentrations of building materials are not applied to light-steel framed buildings until such time as the proper anchoring, bridging, bracing, and staying have been provided.

(b) TRUSSED STEEL RAFTERS indicated for roof framing shall be formed of cold-rolled strip steel weighing not less than 2½

psf before forming, and electric-welded to the sizes, shapes, and types shown. Trussed steel rafters shall be anchored where they bear on steel stud walls by means of bolting or welding; they shall also be braced or strutted laterally between rafters.

(c) STEEL STUD WALL FRAMING shall consist of cold-formed and factory-finished, copper-bearing strip steel weighing not less than 2½ psf before forming, and electric-welded to produce lightweight structural shapes of the nailable type. In general, the framing shall include channel shapes at the bottom and top of all walls, full studs 3⅝-inches depth and spaced not to exceed 16-inch centers; one-half stud; sill members and headers or lintels for exterior openings; anchors, screws, bolts, clips, fasteners, joist hangers, bridging and bracing; and all other fittings and accessories necessary to complete the structural exterior wall framing of the building. All the steel members shall be provided with standard punching to provide for the passage of pipes, conduits, and for anchors, bolts, and connections. All connections shall be made by welding, bolting, sheet-metal screws, or other approved types of fastening that will provide rigidity and conform to the requirements of the manufacturer of the steel framing.

(d) HANDLING AND ERECTION.—Materials shall be unloaded, stored, and handled in a manner, and with appliances and care that will prevent distortion and damage to the members and will keep them clean and drained properly while being stored. After being erected, the various members forming parts of a completed frame or structure, shall be aligned, adjusted, and guyed accurately before being fastened. Fabrication and erection shall be in accordance with the manufacturer's recommendations.

5–07. PAINTING.—All surface of metal work shall be cleaned and given a shop coat of rust-inhibitive paint of the type standard with the manufacturer. All metal surfaces that will be in contact with concrete or masonry, and all metal surfaces that will be concealed or will be inaccessible for painting after erection, shall be given an additional field coat of the same paint prior to erection.

5–08. METAL WINDOWS.

(a) GENERAL REQUIREMENTS.—Windows shall be of the casement type known commercially as "residence type" and shall be of steel or aluminum construction. All windows shall be complete with hardware weatherstripping, operating mechanisms, anchors, glazing clips, screens, and all other appurtenances necessary for their proper installation and operation. Shades and drapery brackets, and drilled and tapped holes for venetian blinds shall be provided on all window frames.

(b) CASEMENT WINDOWS.—Hardware shall be of steel, malleable iron, or aluminum, and of a type that will control the ventilating sections independently of the insect screens. Each ventilating section shall be provided with cam-acting locking handles, extension-type adjustable friction hinges to hold the sash in the open position at any point and permit window cleaning from the inside. Friction-type bar operators and adjusters at the sill, operating through or under the screens, may be provided in lieu of the friction-type hinges. Full-length nonferrous metal wire cloth insect screens of a type standard with the manufacturer, fixed in position with spring clips for easy removal, shall be provided for all ventilating sections; small wickets shall be provided opposite the cam locking handles. Steel windows and insect screen frame shall be factory-finished with a baked-on rust inhibitive coat of paint. Windows shall be installed in a proper manner, square, plumb, and in true alignment without wedging or twisting, so that they are weather-tight and will operate easily and close and lock tightly without forcing. If aluminum windows are used, all surfaces that will be in contact with concrete, masonry, or other metals shall be coated with an approved bituminous paint before being installed. If aluminum windows are used, all aluminum surfaces shall be protected in approved manner before the plastering is started to prevent damage or discoloration by plaster droppings or spatterings. All window frames shall be bedded in a waterproof mastic compound when being set and all openings shall be calked, using a pressure gun and a waterproof mastic calking compound.

SECTION 6. CARPENTRY AND JOINERY

6–01. GENERAL REQUIREMENTS.—All framing, rough carpentry, and finishing woodwork required for the proper completion of the building shall be provided. All woodwork shall be protected from the weather, and the building shall be thoroughly dry before the finish is placed. All finish shall be dressed, smoothed, and sandpapered at the mill, and in addition shall be hand smoothed and sandpapered at the building where necessary to produce proper finish. Nailing shall be done, as far as practicable, in concealed places, and all nails in finishing work shall be set. All lumber shall be S4S; all material for millwork and finish shall be kiln-dried; all rough and framing lumber shall be air- or kiln-dried. Any cutting, fitting, framing, and blocking necessary for the accommodation of other work shall be provided. All nails, spikes, screws, bolts, plates, clips, and other fastenings and rough hardware necessary for the proper completion of the building shall be provided. All finishing hardware shall be installed in ac-

cordance with the manufacturers' directions. Calking and flashing shall be provided where indicated, or where necessary to provide weathertight construction.

6–02. GRADING.—Material shall be graded in accordance with the latest grading rules of the association under whose rules it is graded, and shall be grade- and trade-marked. Dressed sizes (after surfacing) shall be not less than those conforming to American Lumber Standards.

6–03. MATERIALS.—Materials shall be as follows:

(a) WHITE PINE OR PONDEROSA PINE, GRADE C SELECT, OR CYPRESS GRADE C, for all trim or finish not specified otherwise on the exterior of the building; for all exterior door and window frames and staff beads.

(b) WHITE PINE OR PONDEROSA PINE, No. 1 CUTTINGS, for all exterior wood doors and sash not specified otherwise.

(c) WHITE PINE, PONDEROSA PINE, OR CYPRESS, GRADE C OR C SELECT, for all interior trim and finish not specified otherwise.

(d) YELLOW PINE OR DOUGLAS FIR shall be used except where other species of wood are specified. All framing and concealed lumber shall be nonstress grade, sound, and equal to grade 1 yellow pine or Douglas fir.

(e) OTHER SPECIES OF LUMBER OF COMPARABLE GRADE may be substituted for the species specified for exterior and interior trim and finish and for framing lumber, if suitable and approved.

(f) OAK, WHITE OR RED, OR NORTHERN HARD MAPLE second grade for finish wood floors where exposed.

6–04. FRAMING.—Locations, dimensions, or arrangements of framing members not indicated shall be as necessary for their purposes. Spiking, nailing, and bolting shall be done in a substantial manner. Timbers shall be drilled accurately for bolting; suitable washers shall be provided and all bolts shall be drawn up tightly. Wood framing shall be kept not less than 2 inches away from chimney.

6–05. SILLS, PLATES, AND GIRDERS shall be anchored to the concrete or masonry construction; where sizes of bolts are not shown they shall be not less than ½ inch in diameter, about 22 inches long, and spaced at not over 6-foot centers. Sills and plates shall be lapped at corners of building and at splices, and shall be bolted through the laps, or the ends shall be butted and bolted not more than 6 inches from the ends. Girders shall be anchored to the piers and walls with bolts or U-strap anchors. Girders, sills, and plates shall be bedded solidly in 1 to 3 cement mortar to form a level and continuous bearing.

6–06. FLOOR JOISTS AND ROOF RAFTERS shall be of uniform widths; they shall have full bearing on walls, sills, plates, and girders, and shall be spiked at laps; laps shall be made only at bearings. Joists parallel with and directly under partitions shall be doubled; where pipes are in partitions, double joists shall be arranged to provide

proper clearances. Cross-bridging 1- by 3-inch size shall be provided for joists; the distance between rows of bridging, and between bridging and bearings shall not exceed 8 feet. After joists have been set in position properly and cross-bridged, the tops shall be level; only nonshrinkable shims shall be used for leveling joists. Trussed wood rafters shall be fabricated approximately as indicated and shall be set and anchored as specified for floor joists; look-outs shall be spiked to the sides of trussed wood rafters to provide forming for boxed cornices. Joists supporting wood subfloors under concrete floor fill at the heater room shall be installed at the proper elevation below the finish floor. Steel joist hangers shall be provided for framing around chimneys, openings through the floor, and at the other locations as necessary. Floor joists shall be anchored to the masonry walls at sides and ends, using the strap anchors specified under the section entitled "Miscellaneous steel and iron work." Lateral wood bracing and ridge shall be provided between the wood rafters. (The counterceiling of the joists to receive the tile floor in the bath room is specified under the section entitled "Tilework.")

6–07. Studding for walls and partitions shall have doubled plates and doubled stud caps. Studs shall be set plumb at not to exceed 16-inch centers and in true alignment; they shall be bridged with one row of 2- by 4-inch pieces, set flatwise, fitted tightly, and nailed securely to each stud. Studding shall be doubled around openings and the heads of openings shall rest on the inner studs. Openings in partitions having widths of 4 feet and over shall be trussed. In wood frame construction, studs shall be trebled at corners to form posts.

6–08. Sheathing and subflooring shall be 1 by 6, nominal size tongued-and-grooved, or square-edged boards, shall be applied diagonally, and nailed tightly with not less than two 8-penny nails at every bearing; end joints shall be made with a bevel cut and shall occur only over bearings. Wood roof sheathing shall be laid at right angle to the rafters. Wall and roof sheathing shall be covered with 15-pound saturated felt, lapped at least 4 inches at side and end joints, and nailed sufficiently to hold it in place before the roofing and siding are applied. Subflooring shall be covered with a waterproofed building paper before the finish wood flooring is laid.

6–09. Exterior wall finish shall be cement-asbestos shingles 24 by 12 inches, and shall have a uniform thickness of not less than $\frac{5}{32}$ of an inch. Shingles shall have even or wave line butts, and shall be light gray or white, with a baked-on ceramic finish. Shingles shall be nailed with nonferrous metal nails of the size and type recommended by the manufacturer, with a 10-inch exposure to the weather, and a $1\frac{1}{2}$-inch lap over the course laid previously. Vertical joints shall be protected with felt-backed strips not less than 3 by 12 inches.

Nonferrous metal flashing strips shall be applied over the heads of all window and door openings and mastic calking compound shall be applied around all window and door openings before the cement-asbestos shingles are applied. Nonferrous metal corner beads shall be applied at all external angles before shingles are applied.

6–10. ASPHALT SHINGLE ROOFING shall be 12- by 36-inch strip shingles, weighing not less than 210 pounds per square, laid with a 5-inch exposure to the weather, and with a 2-inch headlap. Asphalt shingles shall be 3 or 4 tab, square butt, standard or thick butt shingles, and they shall be of the color selected. Shingles shall be nailed with large head zinc-coated steel roofing nails in accordance with the recommendations of the manufacturer. Asphalt shingle roofing shall be applied over the bituminous saturated felt specified hereinbefore. Ridges shall be covered with individual shingles, or with 10-inch wide strips of mineral-surfaced roll roofing to match the shingles as closely as practicable. Flashings around chimney shall be zinc-coated sheet steel weighing not less than 1 pound per square foot before coating and forming. The head of each roofing nail shall be coated with a mastic roofing cement before the succeeding course of shingles is laid.

6–11. THERMAL INSULATION shall be provided over the entire ceiling of the building; it shall consist of 2-inch thick mineral wool or fibrous glass in roll form and of a width to fit between the trussed rafters, with extended flanges for nailing in position. The insulating material shall be covered on the room side with an approved vapor-barrier material. In spaces where it is impracticable to use roll-type insulation, poured insulation of similar material shall be provided to a thickness of not less than 4 inches.

6–12. WOOD BUCKS, FURRING STRIPS, AND GROUNDS.—Wood bucks not less than 1⅝-inches thick shall be provided around openings in masonry walls where necessary to provide nailing for frames and trim. Wood furring strips of 1- by 2-inch nominal size material and spaced not to exceed 16-inch centers shall be applied in a vertical position to all masonry walls that are to be plastered; they shall be plumb, square at the corners and at the ceiling, and shall be secured to the masonry walls by means of heavy cut nails, or concrete nails to provide firm anchorage. Plaster grounds shall be 1- by 2-inch nominal size, and shall be provided around all openings for trim, for baseboard, and other finished woodwork, and elsewhere as required for the support of fixtures, shelving, and other work. Edges of plaster grounds shall be placed not less than ¼-inch back from the outer edge of the trim so as to be concealed.

6–13. DOOR FRAMES in exterior walls shall be not less than 1⅝ inches thick and shall be double rabbeted in the solid wood; separate staff beads shall be provided for frames in masonry walls. Frames for

interior doors shall be not less than $25/32$-inch thick with $1/2$- by $1\frac{5}{8}$-inch applied rabbet strips. Wood sills shall be not less than $1\frac{5}{8}$-inches thick.

6–14. Wood double-hung windows, complete with frames, sash, hardware, spring sash balances, weatherstripping, and of fenestration similar to that indicated, may be provided in lieu of the steel casement windows; sash shall be not less than $1\frac{3}{8}$-inches thick and the double-hung windows shall conform to the requirements of the National Woodwork Manufacturers Association. Full-length wood frame window screens $25/32$-inch thick shall be provided for all window openings; screen cloth shall be nonferrous metal as specified for the steel casement windows; all hardware and accessories shall be included.

6–15. Doors.—Exterior doors shall be not less than $1\frac{5}{8}$-inches thick and interior doors shall be not less than $1\frac{5}{16}$-inches thick, conforming to the requirements of the National Woodwork Manufacturers Association. Exterior doors shall be glazed as indicated, and shall be of solid wood construction. Interior doors shall be of the flush type, either softwood or hardwood veneered. Door between kitchen and living-dining room shall have a small vision panel in the upper part of the door. The edges and room side of the door to the heater room, and the exposed surfaces of the frame and trim shall be covered with black sheet steel weighing not less than 0.75 psf, applied over one thickness of $1/16$-inch thick asbestos paper. Trap door to roof space and trap door to crawl space shall be provided in the large closet between the bedroom and bath; trap doors shall be constructed of $3/4$-inch thick plywood, or of flooring material with wood battens on the underside. Small plywood closure panels shall be provided on the interior face of the louvered vents in the gable ends of the roof space; they shall be held in place by means of steel wire hooks and eyes, or by small hinges and a latch.

6–16. Finish wood flooring shall be tongued-and-grooved, not less than $25/32$-inch thick by $2\frac{1}{4}$ or $3\frac{1}{4}$ inches wide. Hardwood flooring shall be provided for the living-dining space, rear hall, and for the bedroom; softwood flooring shall be provided for the kitchen and closets. (Bathroom will have a tile floor.) Sections with knotholes, or loose knots shall be cut out. Flooring shall be jointed neatly, driven up tightly, and secret nailed, using 8-penny flooring nails. All finish flooring shall present smooth, level, and even surfaces; hardwood flooring shall be machine-sanded ready for the application of penetrating floor sealer. (Concrete floor slab will be exposed in the heater room.)

6–17. Exterior trim and finish.—Boxed cornices shall be provided on front and rear elevations, formed of $25/32$-inch thick material; fascia

shall have a drip at the lower edge. Bed moldings shall be provided under the roofing and at the junction with wall. The verge board running up the rake of the gables shall be 25/32-inch thick with bed moldings to member with those on the cornice. The soffit of the cornice shall be provided with 4 openings on each of the front and rear elevations; openings shall be about 3 by 12 inches and shall have insect screens provided over the interior of the opening. Louvers in gable ends shall have 1 1/8-inch thick frames and 25/32-inch thick louver vanes set at a 45 degree angle and overlapping in a manner to exclude rain and snow; closure doors as specified hereinbefore and insect screen cloth shall be provided on the interior.

6–18. Interior finish and trim.—Trim for doors, windows, and other openings, including those for metal windows, shall be of plain or molded pattern not less than 25/32-inch thick, and shall be mitered neatly at angles. Window stools and aprons shall have neatly-returned ends. Door and opening trim shall terminate at the floor. Baseboard and shoe moldings shall be provided for all rooms and spaces; baseboard shall be 25/32-inch thick, about 3 3/4-inches high. Shoe molding shall be neat quarter round and where practicable shall be nailed to the floor and not to the base. Base and shoe moldings shall be coped at internal angles and mitered at external angles. Thresholds shall be provided at front and rear exterior doors, at the door to the heater room, and at any other locations where different floor materials adjoin; they shall be about 5/8-inch thick, shall have beveled edges, and shall be fitted neatly and secured properly in place. Each closet shall be provided with wood shelving; not less than 2 rows of shelving shall be provided in the room closets; linen closet shall have shelving from floor to ceiling, with the lower 2 shelves the full depth of closets and upper shelves about 11 5/8-inches deep. Hook boards and clothes poles shall be provided in room closets. Surface-mounted, factory-finished, wood or metal medicine cabinet shall be provided for the bathroom; it shall be about 16 inches wide by 24 inches high, shall have movable glass shelves with rounded edges on the interior, and a hinged plate glass mirror door with a friction catch. Wood or metal kitchen cabinet shall be provided across one end of the kitchen; lower section shall be about 3 feet high, with drawers below the counter, and with cupboard doors of the flush type to the space below the drawers; upper wall section shall be about 13 inches in depth and 30 inches in height, and provided with shelves and with flush solid doors. Hinges, catches, latches, and pulls of the concealed type shall be provided. The counter shelf shall be covered with 1/16-inch thick, black, or red, inlaid linoleum, cemented in place with a waterproof adhesive, and with chromium-plated moldings at the front and rear end along the ends of the counter. Base

cabinet shall be provided with a toe-space at the floor, and with a false bottom. At the right-hand end of the counter a full height utility cabinet shall be provided; the lower section shall be of a height to accommodate ironing board, brooms, and mops, and the upper section with shelf space. All drawers shall be provided with metal or hardwood guides of a type that will hold them rigidly when in an extended position. All kitchen cabinet units shall be factory finished with a baked-on white enamel finish on all exposed surfaces interior and exterior.

6–19. Calking compound shall be provided around all exterior openings; it shall be applied with a pressure gun in a manner to provide weathertight construction.

6–20. Weatherstripping of the spring bronze, nonhumming type shall be applied to exterior door frames; small brass threshold strip, with an engaging hook strip that will be applied to the bottom edge of doors, shall be provided for exterior doors.

6–21. Screen doors having wood frames not less than 1⅟16-inches thick shall be provided for the exterior doors; the insect screen cloth shall be nonferrous metal and as specified for the metal windows. Each door shall be provided with butts, screen door latch and lock set, and with stretch spring closers.

6–22. Priming.—All finish woodwork shall be given an all-over priming coat of white lead and oil paint at the shop before delivery to the building. All parts that will be built in the exterior walls, or will be concealed, shall receive an additional coat of the same paint either at the shop, or in the field before installation. The pulley stiles of double-hung windows shall be given two coats of boiled linseed oil in lieu of the priming coat of paint.

SECTION 7. LATHING AND PLASTERING

(a) Lathing.—All interior walls, partitions, and ceilings shall be lathed with ⅜-inch thick gypsum lath (except when supports or bearings are more than 16-inch centers when ½-inch thick gypsum lath shall be used), 8 inches in length and 16 or 24 inches in width; gypsum lath may be either the plain type, or the perforated type. Gypsum lath shall be applied with its face side out, and with the long dimension at right angles to the framing members; end joints shall be staggered. Gypsum lath shall be nailed with 1⅛-inch long nails of a type approved by the manufacturer and at approximately 5-inch spacings; nails shall not be closer than ⅜ inch from edges or ends, and there shall be not less than 4 nails per support for 16-inch wide lath and 5 nails per support for 24-inch wide lath. Gypsum lath shall be applied with approximately ¼-inch open joints between the ends and sides of the adjoining lath. Strips of painted expanded metal lath shall be applied over the gypsum lath at all vertical and horizontal corners and angles,

and over any chases or openings in the gypsum lath. Upon completion all lathed surfaces shall be plumb, level, and in true alignment, with square corners and angles. Zinc-coated metal corner beads with expanded wings shall be applied to all vertical external angles.

(b) PLASTERING shall be applied in scratch and brown coats, applied by the laid-on or doubled-up method, and using gypsum hardwall plaster, with a hydrated lime white coat finish. Plaster shall be mixed and applied in strict accordance with the manufacturer's instructions, shall be shoved up hard, and shall be filled out to plaster grounds. White coat finish shall be not less than 1/16-inch thick, shall be troweled hard and smooth, and shall be free from waves, irregularities, cat faces, checks, cracks, or blemishes of any sort. Plastering shall not be done in freezing temperatures, nor when freezing can be anticipated, unless the house is closed in and temporary heating is provided by the contractor. Care shall be taken to prevent the plastering from drying out too rapidly. Ventilation shall be provided to prevent sweating. At the option of the contractor, the interiors of all closets may be finished by the "dry-wall" method in lieu of plastering, using 3/8-inch thick gypsum wall board with taped joints and angles, applied in accordance with the manufacturer's instructions.

(c) HEATER ROOM PLASTERING.—Walls, partitions, and ceilings shall be lathed with expanded metal lath weighing not less than 3.4 pounds per square yard. Plastering shall be portland cement mortar, mixed in the proportions of 1 part cement to 3 parts sand, and adding not more than 10 pounds of hydrated lime added in the dry form to the mix. Cement mortar plaster shall be applied in not less than 3 coats to an overall thickness of not less than 3/4 of an inch and shall have a wood float finish.

SECTION 8. TILE WORK

8–01. Bathroom floor shall be counterceiled to a depth of 4 inches below the finished floor level; 1 by 3 cleats shall be nailed to the sides of the joists and 1-inch nominal thickness boards cut between the joints, nailed securely, and covered with saturated roofing felt. The tops of the floor joists shall be cut to about a 45 degree bevel. On top of the false flooring, a 2¾-inch thick concrete fill shall be provided and brought to a level to receive the cement-mortar tile-setting bed. Floor tile shall be vitreous ceramic mosaic of size, pattern, and color to be selected, set in a cement-mortar bed, and grouted upon completion with white portland cement. Tile base with a cove at floor and a rounded top shall be provided. The walls at the back and ends of the tub shall be tiled to a height of 7 feet above the finished floor line, using 4¼-inch square matte-glazed tile, with rounded edges. Wall tile shall be floated on a cement-mortar plaster applied to an

expanded metal lath base. Joints shall be grouted with white portland cement mortar. The bottom course of tile at the bath tub rim shall be set in an approved water-proof plastic compound. All tilework shall be cleaned thoroughly upon completion.

8–02. Bathroom accessories.—One combination tile built-in safety bar and soap dish shall be provided in the tile wall above the bath tub. A soap dish with a removable tray and combination toothbrush and tumbler holder shall be provided over the lavatory; a roll toilet paper holder shall be provided near the water closet; two 24-inch towel bars shall be provided, one on the back of the bathroom door and one on the wall behind the door; one robe hook shall be provided on the interior side of the bathroom door. All of the accessories, with the exception of the built-in tile fixture over the bath tub, shall be of wrought brass, chromium-plated, and shall be of the surface mounted type, with concealed fastenings.

SECTION 9. ASPHALT TILE FLOORING

9–01. Asphalt tile flooring shall be provided in the kitchen, and for all floor surfaces (except bathroom and heater room) where concrete floor fill over steel bar joists is used. Asphalt tile shall be 3/16-inches thick, 9- by 9-inch size, with 6-inch wide black borders; the field tile shall be a medium-light marbelized or mottled color as selected. When asphalt tile flooring is to be laid over wood subfloor, one ply of saturated felt shall first be applied, cemented with an approved adhesive. Asphalt tile shall be laid in an approved mastic compound, of a type recommended by the manufacturer. The completed floor shall be cleaned thoroughly, waxed, buffed, and protected with a suitable covering until ready for occupancy. Plastic tile 1/8-inch thick may be substituted for the 3/16-inch thick asphalt tile specified.

SECTION 10. GLAZING

10–01. All doors that are to be glazed and all windows shall be glazed with double strength "B" quality sheet glass. All glass shall be bedded, back and face puttied, using best grade pure linseed oil and whiting putty. All muntins shall be painted before glass and putty are applied. Glass in doors shall be bedded in putty, and shall be held in place by means of wood glazing beads. Upon completion, all glass shall be washed clean, and any cracked or broken glass replaced with new lights of glass.

SECTION 11. FINISHING HARDWARE

11–01. Finishing hardware shall be provided for all exterior and interior doors. (Hardware for metal windows, wood double-hung windows, insect screens, and screen doors, and for kitchen cabinets

is specified under other sections.) All butts and hinges shall be of wrought steel with a prime finish for painting; 1½ pairs of butts shall be provided for exterior doors, and one pair of butts for all interior doors. All other finishing hardware shall be of wrought steel with a plated finish to match approved samples; chromium-plated finish shall be provided for kitchen and bathroom. Exterior doors shall each be provided with a five pin tumbler mortised cylinder lock set, with dead bolt in addition to the latch bolt, complete with knobs and roses. Each interior door shall be provided with a mortised latch set, complete with knobs and escutcheons. Doors to bedroom and to bathroom shall each have a mortised lock set having a dead bolt that is operated from inside the room by means of a thumb turn, and with provision for emergency key operation from the outside. Tubular latch and lock sets of comparable quality may be substituted for the hardware specified for the interior doors. Each room closet shall be provided with eight cast or wrought coat and hat hooks. Door stops shall be provided for all locations where doors will contact the finished wall surfaces. A mail slot, with spring-hinge actuated leaf to close the opening, shall be provided in the front door. Door closer of the proper size shall be provided for the door to the heater room.

SECTION 12. PLUMBING

12–01. General requirements.—The work consists of a complete plumbing system including the sanitary soil, waste, and vent piping; cold and hot water supply piping, water meter (if required), plumbing fixtures, hot water heater, and other necessary appurtenances. The system shall be inspected, tested, and approved by local governing plumbing codes before burying, concealing, or covering the various piping systems. Each system shall be complete and ready for operation except as specified or indicated otherwise.

12–02. Sanitary sewer, below ground level, shall be of extra heavy cast iron soil piping and fittings of the bell and spigot type extending not less than 5 feet beyond the foundation wall and graded not less than ⅛ inch per foot. The joint shall be made from a good grade twisted oakum uniformly and well tamped into the joint and with a 1 inch depth of hot poured lead, made in one pouring, and calked tight. All horizontal soil connections to the system shall be accomplished by Y-fittings or combination Y and ⅛-bends and all changes in direction greater than ⅛-bends shall be of the long sweep pattern. Lines shall be well supported to eliminate sagging. Backfilling shall be well tamped in 6-inch layers.

12–03. Sanitary sewer, above ground, shall be as specified for below ground except wastelines and vent piping above ground shall be of zinc coated, standard-weight, screwed-end steel pipe and cast iron recessed long radius screwed drainage fittings, graded not less

than ⅛ inch per foot. The sanitary sewer vent shall extend full size through the roof for a distance of not less than 12 inches where it shall be flashed with suitable corrosion-resistant metal before the roofing is installed. A 4-inch cleanout shall be provided just above ground elevation at the base of the vent stack. All male screw ends shall be coated with a good grade pipe joint compound before entering into fittings. The bathtub trap shall be provided with a ¾-inch brass screw drain plug; all lines shall be properly supported from the floor joints with suitable hangers. Closet-bowl floor connection shall have a cast-iron closet-bowl floor flange with provisions for anchoring the brass closet-bowl bolts and an approved-type horn gasket. The finished joint shall be absolutely leak-proof and the bowl shall sit squarely on the finished floor.

12–04. WATER PIPING BURIED IN THE GROUND shall be jointless type-K soft copper tubing. No "kinking" of the tube will be allowed.

12–05. WATER PIPING ABOVE GROUND shall be type "L" hard copper tubing with solder type fittings, except vertical lines may be of type "L" soft copper tubing. All tubing lines shall be properly anchored to the floor joists to eliminate "pipe hammering" and pitched to the main shut-off valve for draining when necessary. A hose bibb shall be provided at the rear of the building with a stop and waste located inside the foundation wall for winter cut-off and waste and arranged for complete drainage of the line from the hose bibb. Slip joint connections will not be permitted below finished floor.

12–06. FIXTURES shall be of a reliable manufacturer and shall be as follows:

(a) KITCHEN SINKS shall have a left-hand drainboard and be of cast iron with a smooth, white, acid-resisting porcelain enamel finish, 54 inches long by 25 inches wide by 36 inches from floor to top of rim. The trim shall be chromium plated including combination mixing faucets with soapdish, large basket type strainer with 1½-inch tail piece, and a 1½-inch wall type P-trap. Hot and cold water supply lines in the sink cabinet shall be provided with copper tubing stops. The cabinet shall be of a heavy gage steel with a baked-on white enamel finish and have at least two sliding drawers.

(b) LAUNDRY TRAY shall be double compartment cement type, 48 inches long by 20 inches wide by 32 inches high from floor to rim and be of a smooth cement mixture to withstand sudden temperature changes without cracking or leaking. Tubs shall have a metal guard around their rims. The laundry tray shall be complete with stand, combination mixing faucets with tray mounting brackets, 1½-inch tail-pieces, and 1½-inch wall type P-trap. A copper tubing stop shall be provided in each supply line.

(c) WATER CLOSET shall be of white vitreous china, close-coupled tank and bowl, complete with white seat and seat cover, and have a chromium ⅜-inch screwed brass floor supply pipe with a chromium I. P. stop.

(d) LAVATORY shall be cast iron with a white porcelain enameled finish. The trim shall be chromium-plated and shall include combination mixing faucets with a 1¼-inch tail piece, pop-up waste, 1¼-inch wall trap, and ⅜-inch screwed brass floor supplied with I. P. stops.

(e) TUB shall be built-in type, cast iron, with a white porcelain enameled finish. The trim shall be chromium-plated and include a built-in wall type faucet complete with shower attachments, curtain rod and pins, and a 1½-inch trip-lever waste. Copper tubing stops shall be provided on each supply inside the wall access door.

12–07. WATER HEATER shall be of the electrical storage type with a capacity of not less than 52 gallons. It shall be of an approved manufacturer with the underwriter's label attached. It shall be provided with two thermostatically operated heating elements: a 1500-watt element located near the top and a 1000-watt element located near the bottom of the tank. A ¾-inch bronze drain valve shall be provided at the extreme bottom of the tank with a ¾-inch hose connection. A ½-inch brass pressure relief valve with discharge extend to floor drain shall be furnished. A check valve of all bronze construction and a copper tubing stop shall be installed in the cold water supply. Electrical work shall conform to the local governing electrical codes.

12–08. A main shut-off valve shall be installed as indicated or specified. The 1-inch main shut-off valve shall be accessible, of the stop and waste pattern with soldering type ends, and the waste arranged for complete drainage of the entire water supply system.

12–09. WORKMANSHIP shall be performed in a first class manner observing all standards of good installation practices.

12–10. TESTS shall be conducted on all plumbing systems to provide tightness of all piping joints. If leaks occur, they shall be repaired immediately and the tests repeated. The soil, waste, and vent systems shall be completely filled with water to the highest point before checking for leaks. The hot and cold water piping shall be tested with water at one and a half times the working pressure. After all tests have been proven satisfactory, all necessary adjustments on the faucets, traps, valves, and other specialties shall be checked in order that the entire systems can be placed in normal operation.

12–11. INSULATION.—All piping and fittings subjected to freezing temperatures shall be adequately insulated with a suitable frost-proof covering, well secured in place.

SECTION 13. HEATING

13–01. General requirements.—The work shall consist of furnishing and installing all heating material, equipment, and other necessary appurtenances to assemble a complete low-pressure forced-circulated hot water heating system as indicated. The system shall be tested, inspected, and adjusted to provide satisfactory trouble-free heating under the most severe local winter conditions that might be encountered.

13–02. Design.—The designed outside temperature is zero degrees F. and the heating system shall maintain, under all designed conditions, an inside temperature of not less than 75 degrees F. For designed conditions other than the above, the following adjustment factors shall apply to increase or decrease boiler, radiation, and pipe sizing as local climatic conditions require:

Degrees F	Percent to be added	Percent to be deducted	Pipe main size
−30	42	--------	1¼
−20	28	--------	1¼
−10	14	--------	1
+10	--------	14	1
+20	--------	28	¾
+30	--------	42	¾

Boiler operating controls shall be set at 210 degrees F.

13–03. Boiler.—The heating unit shall be installed as directed and shall be an oil-fired welded steel or cast-iron sectional boiler of the package-unit type. It shall be furnished complete with all necessary electrical operating controls for winter operation, combustion chamber, insulation, jacket, temperature, pressure and altitude gage, and other necessary appurtenances. The boiler shall have the A. S. M. E. label and the oil burner and controls shall have the underwriter's label. The boiler-burner unit and accessories shall be of an approved type and of a reliable manufacturer. Boiler shall have provisions for a built-in type domestic direct or indirect water heater.

13–04. Radiation.—The radiators shall be the modern, slenderized, cast-iron tubular type and shall be installed as directed and shall have one primer coat. All radiators shall have an angle type, ½-inch hot water, full-opening, bronze valve on the supply line and a ½-inch, bronze, union elbow on the return line with an adjustable flow de-

vice. Key-type nickel-plated brass air valves shall be provided on all return sections. Each radiator shall pitch slightly upward to its air valve.

13–05. PIPE AND FITTINGS.—All heating piping shall be of black standard steel pipe and all fittings of standard 125-pound cast iron, unless otherwise specified. All pipe threads shall be fully cut clean threads and the pipe end reamed to full size. A good pipe-joint compound shall be used on all pipe threads before entering into fittings. Joints shall be pulled up tight but not strained by using extra leverage on pipe wrenches. All pipe cuts and fittings shall be free of threading chips, reaming chips, dirt, scale, and other foreign matter before assembling. The assembled pipe and fittings shall be given one coat of asphalt base paint before the insulating covering is installed. The piping shall be properly anchored to the floor joists by suitable hangers and shall be graded upward from boiler to radiators so as to extract all the air from the piping when filled with water; the pipe grading shall also allow for complete drainage when the system might be placed out of operation during freezing weather. Where piping passes through floors, walls, or partitions, the pipe shall be centered and have proper clearance around it to prevent a creeping noise when the piping expands and contracts. All branches shall be taken from the top of the main line and provided with proper fitting arrangement for expansion and contractions.

13–06. INSULATION.—All supply, return, radiator feed and return lines shall be properly insulated with 3-ply asbestós air cell covering of an approved or reliable manufacturer, except radiator connections above the finished floor, which shall be painted with the same paint as the finish coat on the radiators. The insulation shall be of the same size as the pipe it is to insulate and shall be secured in place by staples and metal bands placed every 12 inches. All fittings shall be covered with a loose asbestos mixer to a uniform thickness flush with the pipe covering, and shall be applied in not less than two applications. This mixture shall be of such consistency that the pasty mixture shall adhere permanently to the fitting.

13–07. FLOOR PLATES.—Where a pipe passes through a floor, a wall, or a partition, it shall be fitted with the same size chromium or nickel plated split type plate and secured tightly around the pipe.

13–08. HEATING SPECIALTIES.—Specialties shall be of an approved and reliable manufacturer, good design, and suitable for disassembling and repairing without disconnecting from the piping system. Specialties shall be painted and be as follows:

(a) PUMPS.—The pump shall operate quietly at operating conditions, be capable of supplying the required gpm of water for

the various heating loads and produce the proper pressure head. It shall be installed in the return line at an accessible place near the rear bottom connection to the boiler and produce flow as indicated with union connections at each end. The motor shall be suitable for 110-volt 60-cycle current and have the underwriter's label attached. The pump body shall be of cast iron and the impeller of bronze.

(b) FLOW CONTROL VALVE.—The flow control valve shall be of the correct size, angle type, cast iron body, with bronze working parts, provided with ½-inch compression tank connections, and equipped for manual opening and closing of the valve. It shall be installed in the supply main near the top connection of the boiler.

(c) COMPRESSION TANK.—The tank shall be properly sized to suit the job requirements and shall be secured to the boiler room ceiling. It shall be provided with a ½-inch drain and have a ¾-inch hose connection. Expansion piping from flow valve to tank shall be valveless.

(d) AUTOMATIC FEED AND EXPANSION VALVE.—The valve shall be a combination unit with ½-inch iron pipe connections. The expansion connection shall extend to the floor where it shall drip into a 10-quart bucket. The feed valve shall be set to maintain a pressure of 5 psig when the system is cold; the expansion valve shall relieve pressure at 30 psig. The valve unit shall be installed at the same elevation as the boiler pressure and temperature gage.

(e) RETURN VENTURI FITTINGS.—Each radiator return line shall enter the heating main with the proper and approved type venturi tee of cast iron with iron pipe threads.

13–09. BALANCING COCKS.—The cocks shall be of all bronze or brass construction and shall be properly adjusted after system is placed in operation to distribute the correct amount of hot water to each of the divided mains.

13–10. ELECTRICAL WORK.—All electrical wiring of heating controls shall conform to governing local electrical codes.

13–11. FLUE PIPING.—Flue piping shall be of the same size as the boiler outlet and shall be of 26 gage, or less, galvanized sheet steel properly supported in place. Boiler shall be placed so that not more than two adjustable type elbows shall be used. A barometric balanced type draft regulator shall be installed near the chimney and the oil-burner safety stack control shall be installed near the boiler outlet or as manufacturer's recommendations indicate. All joints shall

fit snug and be sheet metal screwed or bolted in place. Chimney opening around pipe shall be sealed with asbestos cement.

13–12. Oil tank.—The oil tank shall be coated with an asphalt base paint before being buried at the rear of the building and be suitably located for convenient connections to the oil burner. It shall be underwriters approved, 12-gage steel, and properly buried and anchored in the ground. The fill line shall be 2 inch and extended underground to a point where the oil supplier can reach it with his fill hose and be provided with a fill-type key cap. Convenient means shall be provided for checking the oil level in the tank with an accurately graduated dip-stick. The vent line shall be 1¼ inch and extended underground to the rear of the building and projected upward against the rear side to a point above the window tops where a screen-type vent fitting shall be installed and secured. This fitting shall not be closer than 3 feet to any window. Fill and vent lines shall be taken from the tank top and shall have clean-cut full-length threads with the pipe ends reamed to full size. The lines shall pitch slightly to the tank. The pipe shall be of standard galvanized steel pipe with standard galvanized malleable iron fittings. Swing joints shall be provided at the tank. All threaded pipe ends shall be coated with a good grade oil-resisting compound before starting into the fittings. Unused tank connections shall be tightly plugged. The supply and return piping to the burner pump shall be ½-inch type "K" jointless, unkinked, soft copper tubing with flare type fittings at the ends. The holes where the oil lines enter the foundation wall shall be sealed water tight. All piping shall be well supported and strapped in place where necessary.

13–13. Oil line and tank tests.—The oil tank shall be closely checked for shipment damage before burying in the ground. All piping shall be left uncovered until the system has been in continual service for at least 4 consecutive hours during which time a close inspection of all piping and joints shall be made for leaks. The fill line shall be checked for leaks while the tank is being filled; the connections at the tank and burner pump shall be observed closely while the burner is running. A ball check valve shall be provided in the suction line at the burner pump. The suction line at the tank shall have an extended suction line to within 4 inches of the tank bottom and cut at a 45 degree angle. If leaks occur, they shall be promptly repaired and the test repeated until proven satisfactory at which time back-filling may begin and be well tamped in place. All well piping shall be covered with at least 18 inches of backfill.

13–14. Heating system tests.—The entire piping system and boiler shall be given a hydrostatic pressure test before painting and insulating the piping with the city service pressure available and shall

be not less than 50 psig. The test shall be maintained for a period of 4 consecutive hours during which time all joints shall be checked for leaks. If leaks occur, they shall be immediately repaired and the test repeated until proven satisfactory. The calking of lead strips into the threaded joints to seal leaks will not be allowed nor will any other nonpractical method be permitted. When system is proven free of leaks, burner shall be started and all controls checked for normal operation. A flue gas test shall be run after the burner and system have been working under operating conditions for 2 hours. The overall burner-boiler efficiency shall be not less than 80 percent. Draft, stack temperature, and CO_2 shall be determined with the use of instruments and set according to the recommended practices.

SECTION 14. ELECTRICAL WORK

14–01. General requirements.—The work includes the furnishing and installing of all wires, cables, conduit, and conduit fittings, wiring, wiring devices, panelboards, circuit breaker, switches, junction and outlet boxes, lighting fixtures, lamps, receptacles, cabinets, all grounding, and all other equipment and accessories indicated, specified, or necessary for a complete installation.

14–02. Material and workmanship, unless indicated or specified otherwise, shall conform to specification No. 9Yf and to the standards, codes, regulations, and specifications listed therein. Wiring shall be with type AC armored cable except that ½-inch conduit shall be provided between the telephone outlet and telephone cabinet and for the service connections. Wire in the ground floor or underground shall be type ACL lead covered and armored cable.

14–03. Lighting fixture No. 41 shall be made of nonferrous metal or of ferrous metal with a corrosion-resistant plating; the exterior finish shall be statuary bronze or black as directed. The fixture shall be weatherproof and open at the bottom for relamping. The globe shall be the inside-frosted or diffusing glass type.

SECTION 15. FIELD PAINTING

15–01. General requirements.—Paint shall be applied to dry and thoroughly clean surfaces only, and shall be worked into all joints, crevices, and open spaces. Colors and shades of colors shall match approved samples. Finished surfaces shall be smooth and even, and free from defects. Puttying shall be done with a knife after the priming coats have been applied. Metal surfaces shall be free from rust, dirt, loose and disintegrated paint, grease, and scale, before the field coats are applied. Where shop coats have been damaged, the exposed surfaces shall be touched up with lead and oil paint; except

that surfaces shop primed with bituminous paint, where abraded or damaged, shall be touched up with bituminous paint. Zinc-coated surfaces that are to be painted shall be primed with a coat of zinc-dust, zinc-oxide paint. Samples of all finishes shall be submitted for approval. The number of coats of paint specified shall be the highest quality of the respective kind, shall be the product of an established manufacturer, shall be suitable for the intended purpose, and shall be mixed and applied in strict accordance with the manufacturer's instructions. All paints and finishes shall be delivered in the original unbroken packages bearing the manufacturer's name and brand designation. (The finishing of medicine cabinet and kitchen cabinets is specified under other sections.)

15–02. Exterior painting.—All exposed exterior wood and metal surfaces shall be cleaned and smoothed carefully, and shall be painted not less than two coats of lead-zinc-titanium, and oil paint.

15–03. Interior painting.—All metal surfaces including bare and insulated piping that will be exposed in the crawl space shall be painted one coat of black asphaltum varnish. (Steel bar joists, if used, will not require field painting, except where rusted, or where shop coat is damaged.) All exposed interior wood and metal surfaces (except factory-finished and wearing surfaces) shall be painted one coat of enamel undercoater and one coat of enamel, with an eggshell gloss. Enameled surfaces in kitchen and bathroom shall have full gloss. Radiators and any exposed heated piping shall be finished with two coats of heat-resistant enamel. Interiors of closets shall be finished with two coats of interior oil paint. All interior plastered surfaces shall be given one coat of an approved primersealer paint; all plastered surfaces in the bathroom and kitchen shall be given one coat of enamel undercoater, and one coat of full-gloss enamel; all other plastered surfaces (except the cement-mortar plaster in heater room) shall be finished with two coats of rubber base wall paint. If required, interior wood doors shall have a stained and varnished finish, in lieu of the enameled finish specified; stain shall be a spirit stain applied in one coat, blended, sanded smooth, given one coat of clear shellac, sanded, and finished with one coat of a dull-finish, non-rubbing varnish. Filler shall be provided for open pore woods.

15–04. Wood floor finish.—Wood flooring shall be cleaned thoroughly and shall be finished with not less than two coats of a synthetic resin penetrating floor sealer, natural color. Additional sealer shall be applied to any areas that appear to be insufficiently coated. After the sealer has dried thoroughly it shall be buffed with a motor-driven floor machine to a dull sheen. Floors shall be protected adequately until building is ready for occupancy.

The first step in preparing a bill of material is the TAKEOFF. This means that a listing of the various materials needed for the job is made directly from the detailed plans and specifications. The materials on this list are then grouped as items, the total of each item found, and these totals reduced to customary units and number of units to be used on the job. Finally, the items and the totals are entered in the bill of material, each with its correct stock number as given in the *Catalog of Navy Material*, or with appropriate stock and catalog numbers if the material is listed elsewhere.

The unit term, such as pound, ton, lineal foot, in which the quantity of the item is expressed is very important. Different materials are sold in different units, which are generally accepted in the trade, and when an item is listed in terms of the wrong unit, too much or too little of the particular item may be delivered at the job.

In takeoffs and material estimates, some common causes of error are:

1. Inaccurate arithmetic.
2. Inaccurate copying.
3. Omissions.
4. Failure to allow for wastage or spare parts.
5. Failure to check all computations and results.

Careful estimaters check themselves against items of the specifications to make sure that they have covered everything. If possible, the material list, like the drawings, should always be checked by someone other than the one who makes it.

Steel Construction

In takeoffs of structural steel, each kind of member in terms of structural-shape, size, length in lineal feet, and weight in pound or tons should be listed separately. Weights of any rolled steel shape or of a given quantity of rivets or

TABLE OF BOARD MEASURE

Size in inches	Length in feet										
	10	12	14	16	18	20	22	24	26	28	30
1 x 4	3⅓	4	4⅔	5⅓	6	6⅔	--------	--------	--------	--------	--------
1 x 6	5	6	7	8	9	10	--------	--------	--------	--------	--------
1 x 8	6⅔	8	9⅓	10⅔	12	13⅓	--------	--------	--------	--------	--------
1 x 10	8⅓	10	11⅔	13⅓	15	16⅔	--------	--------	--------	--------	--------
1 x 12	10	12	14	16	18	20	--------	--------	--------	--------	--------
2 x 2	3⅓	4	4⅔	5⅓	6	6⅔	--------	--------	--------	--------	--------
2 x 4	7	8	9	11	12	13	15	16	17	19	20
2 x 6	10	12	14	16	18	20	22	24	26	28	30
2 x 8	13	16	19	21	24	27	29	32	35	37	40
2 x 10	17	20	23	27	30	33	37	40	43	47	50
2 x 12	20	24	28	32	36	40	44	48	52	56	60
2 x 14	23	28	33	37	42	47	51	56	61	65	70
3 x 6	15	18	21	24	27	30	33	36	39	42	45
3 x 8	20	24	28	32	36	40	44	48	52	56	60
3 x 10	25	30	35	40	45	50	55	60	65	70	75
3 x 12	30	36	42	48	54	60	66	72	78	84	90
3 x 14	32	42	49	56	63	70	77	84	91	98	105
4 x 4	13	16	19	21	24	27	29	32	35	37	40
4 x 6	20	24	28	32	36	40	44	48	52	56	50
4 x 8	27	32	37	43	48	53	59	64	69	75	80
4 x 10	33	40	47	53	60	67	73	80	87	93	100

4 x 12	40	48	56	64	72	80	88	96	104	112	120
4 x 14	47	56	65	75	84	93	103	112	121	131	140
6 x 6	30	36	42	48	54	60	66	72	78	84	90
6 x 8	40	48	56	64	72	80	88	96	104	112	120
6 x 10	50	60	70	80	90	100	110	120	130	140	150
6 x 12	60	72	84	96	108	120	132	144	156	168	180
6 x 14	70	84	98	112	126	140	154	168	182	196	210
6 x 16	80	96	112	128	144	160	176	192	208	224	240
8 x 8	53	64	75	85	96	107	117	128	139	149	160
8 x 10	67	80	93	107	120	133	147	160	173	187	200
8 x 12	80	96	112	128	144	160	176	192	208	224	240
8 x 14	93	112	131	149	168	187	205	224	243	261	280
8 x 16	107	128	149	171	192	213	235	256	277	298	320
10 x 10	83	100	117	133	150	167	183	200	217	233	250
10 x 12	100	120	140	160	180	200	220	240	260	280	300
10 x 14	117	140	163	187	210	233	257	280	303	327	350
10 x 16	133	160	187	218	240	267	293	320	347	373	400
12 x 12	120	144	168	192	216	240	264	288	312	336	360
12 x 14	140	168	196	224	252	280	308	336	364	392	420
12 x 16	160	192	224	256	288	320	352	384	416	448	480

bolts in a certain size may be obtained from any good steel construction handbook. Even where a structure is welded, a certain number of bolts, which will be placed in the framework and later removed, are often required. Steel for floating structures is listed in terms of long tons (l. t.), consisting of 2200 pounds; whereas steel for buildings is listed in terms of the standard ton of 2000 pounds.

It is easy to overlook such items as bearing plates, various field connections, gusset plates, field bolts, ties, beam separators, anchors, turntables, etc. Some minor parts or details may not even be shown on the plans or mentioned in the specifications. For this reason, the man who makes structural-steel takeoffs must have a good working knowledge of structural-steel construction.

Wood Construction

The materials for wood construction are various kinds of lumber and necessary nails and hardware. The takeoff may be grouped into such divisions as framing timber, planing, finish materials, nails, hardware, etc.

Lumber is listed by board feet measure. One board foot is the equivalent of a board 1 foot long by 1 foot wide by 1 inch thick. The number of board feet in any piece of lumber is equal to the length in feet multiplied by the width in feet multiplied by the thickness in inches with this product divided by 12, or

$$\text{foot board measure (fbm)} = \frac{L' \times W' \times t''}{12}.$$

Standard lengths are in multiples of 2 feet and generally range from 10 to 20 feet. Standard widths are in multiples of 1 inch.

Trimming material, such as molding, is usually measured by the lineal foot (l. f.). Flooring, plywood, and shingles are sometimes measured by the square foot. Some articles are also measured by the piece.

Dressed lumber will be from ¼ inch to ½ inch less than

the nominal size in width and thickness. In estimating, allowance must be made for such things as sawing, planing, cutting, matching, and lapping. Allow 5 to 10 percent for waste in end cutting.

Nails are usually estimated in pounds at so many pounds to 1,000 feet board measure or at so many pounds to a square of 100 square feet, with consideration for the size of lumber and the kind of construction. The following table, based on a table in *The Building Estimator's Reference Book* by Frank R. Walker, gives the number of wire nails in pounds per 1,000 feet board measure, per 1,000 shingles and lath, or per 100 square feet of asphalt slate surfaced shingle. The unit of measure in the table is 1,000 board feet unless indicated otherwise. The necessary number of nails are added to cover loss of material on account of lap or matching of shiplap, flooring, ceiling, and siding of various widths. The table gives the sizes generally used, with a nailing space of 16 inches on center and 1 or 2 nails to a board for each nailing space.

Description of material	Unit of measure (*feet*)	Size and kind of nail	Number of nails required	Pounds of nails required
Wood Shingles	1,000	3d Common	2, 560	4
Individual Asphalt Shingles.	100 sq. ft.	⅞″ Roofing	848	4
Three in One Asphalt Shingles.	100 sq. ft.	⅞″ Roofing	320	1
Wood Lath	1,000	3d Fine	4, 000	6
Wood Lath	1,000	2d Fine	4, 000	4
Bevel or Lap Siding; ½″ x 4″.	1,000	6d Coated	2, 250	*15
Bevel or Lap Siding ½″ x 6″.	1,000	6d Coated	1, 500	*10
Byrkit Lath, 1″ x 6″	1,000	6d Common	2, 400	15
Drop Siding, 1″ x 6″	1,000	8d Common	3, 000	25
⅜″ Hardwood Flooring.	1,000	4d Finish	9, 300	16
1⅝″ Hardwood Flooring.	1,000	8d Casing	9, 300	64

Description of material	Unit of measure (*feet*)	Size and kind of nail	Number of nails required	Pounds of nails required
Softwood Flooring, 1" x 3".	1,000	8d Casing	3, 350	23
Softwood Flooring, 1" x 4".	1,000	8d Casing	2, 500	17
Softwood Flooring, 1" x 6".	1,000	8d Casing	2, 600	18
Ceiling, ⅝" x 4"	1,000	6d Casing	2, 250	10
Sheathing Boards, 1" x 4".	1,000	8d Common	4, 500	40
Sheathing Boards, 1" x 6".	1,000	8d Common	3, 000	25
Sheathing Boards, 1" x 8".	1,000	8d Common	2, 250	20
Sheathing Boards, 1" x 10".	1,000	8d Common	1, 800	15
Sheathing Boards, 1" x 12".	1,000	8d Common	1, 500	12½
Studding, 2" x 4"	1,000	16d Common	500	10
Joist, 2" x 6"	1,000	16d Common	332	7
Joist, 2" x 8"	1,000	16d Common	252	5
Joist, 2" x 10"	1,000	16d Common	200	4
Joist, 2" x 12"	1,000	16d Common	168	3½
Interior Trim, ⅝" thick.	1,000	6d Finish	2, 250	7
Interior Trim, ¾" thick.	1,000	8d Finish	3, 000	14
⅝" Trim where nailed to jamb.	1,000	4d Finish	2, 250	3
1" x 2" Furring or Bridging.	1,000	6d Common	2, 400	15
1" x 1" Frounds	1,000	6d Common	4, 800	30

*Note.—Cement-coated nails sold as two-thirds of a pound are equal to 1 pound of common nails.

Concrete Construction

The materials for concrete construction include cement, sand, gravel or crushed stone, reinforcing steel, finishing materials, materials for forms, and materials for protection against freezing. On some jobs, it is possible to reuse form

lumber. If readymade wood or metal forms are used, they will usually be classed as construction equipment which can be used over many times and therefore will not go into the list of material for any particular job.

In making the takeoff for concrete work, a good method is to list separately each grade or mix of concrete used. After the takeoff is completed and the total yardage of each grade of concrete is found, the quantities of cement and other ingredients can be computed.

Concrete is measured as fixed or placed in the structure in cubic yards (or cubic feet). Moldings, curbs, gutters, lintels, and such work are often measured by lineal foot with the other dimensions given so that the number of cubic yards or cubic feet may be found. Concrete finishing is measured by the square foot or square yard.

The proportions of a concrete mix are usually expressed as three numbers, thus, 1 : 2 : 4, with the proportion of cement first, the proportion of sand second, and the proportion of gravel or crushed stone third. From these proportions, it is possible to find the quantities of the materials per cubic yard of finished concrete either by referring to tables in handbooks or by the use of formulas.

The table on page 288, from *The Building Estimator's Reference Book* by Frank R. Walker, gives suggested trial mixes and weight of surface dry aggregates required per sack of cement and per cubic yard of concrete. A sack of cement weighs 94 pounds and has a volume of 1 cubic foot.

Note that the table gives the proportions of the mix with surface-dry aggregates. When the aggregates are damp, their weight, as well as their bulk, is increased, and the proportions are different. Tables are also available giving the proportions of concrete mixes in terms of volume.

The amount of water in a concrete mix determines the strength of the cement. Concrete hardens because of a chemical reaction between the cement and the water. The

SUGGESTED PROPORTIONS FOR CONCRETE MIX

Maximum size coarse aggregates (inches)	Water gal. per sack	Quantity aggregates per sack of cement				Quantity of materials per cubic yard of concrete					
		Sand lbs.	Gravel lbs.	Sand lbs.	Stone lbs.	Cement sacks	Sand lbs.	Gravel lbs.	Cement sacks	Sand lbs.	Stone lbs.
¾	5	180	235	175	190	7. 4	1, 330	1, 740	8. 0	1, 400	1, 520
1	5	165	270	165	220	7. 2	1, 190	1, 945	7. 8	1, 290	1, 715
1½	5	160	310	160	250	6. 8	1, 090	2, 110	7. 4	1, 185	1, 850
2	5	160	350	160	290	6. 4	1, 025	2, 240	7. 0	1, 120	2, 030
¾	6	230	280	230	230	6. 2	1, 425	1, 735	6. 7	1, 540	1, 540
1	6	215	320	215	260	6. 0	1, 290	1, 920	6. 5	1, 400	1, 690
1½	6	205	365	210	300	5. 7	1, 170	2, 080	6. 2	1, 300	1, 860
2	6	210	425	210	345	5. 3	1, 110	2, 250	5. 8	1, 220	2, 000
¾	7	285	325	285	265	5. 3	1, 510	1, 725	5. 7	1, 625	1, 510
1	7	270	370	265	300	5. 1	1, 375	1, 890	5. 6	1, 480	1, 680
1½	7	260	420	260	350	4. 9	1, 275	2, 060	5. 3	1, 380	1, 855
2	7	260	480	265	395	4. 6	1, 195	2, 210	5. 0	1, 325	1, 975
¾	8	350	365	345	290	4. 6	1, 610	1, 680	5. 0	1, 725	1, 450
1	8	325	415	320	335	4. 5	1, 465	1, 870	4. 9	1, 570	1, 640
1½	8	315	470	320	395	4. 3	1, 355	2, 020	4. 6	1, 470	1, 820
2	8	320	540	320	440	4. 0	1, 280	2, 160	4. 4	1, 410	1, 935

aggregates are merely fills. The concrete with 5 gallons of water to a sack of cement is much stronger than that with 8 gallons to a sack. The proportion of water will not appear in the bill of materials, but it will appear in the specifications.

For example, in the specifications for a one-bedroom house which are included in this chapter, the statement is made under General Requirements, Section 3, Concrete, "that all concrete shall be proportioned by the volumetric measurements, using 1 part cement to 2 parts of sand and 4 parts of gravel or crushed stone." Also, not less than 5 sacks of cement and not more than 7 gallons of water per sack of cement are to be used for each cubic yard of concrete. The water, it is specified, should be potable, that is, pure enough to drink. The coarse aggregates shall be of a size that will be retained on a ¼-inch screen and will pass a 1-inch screen.

Reinforcing steel is usually estimated by weight, assuming that a square bar 1 inch by 1 inch by 12 inches long weighs 3.4 pounds. Reinforcing bars should be listed as plain bars, deformed bars, spirals, round or square bars of different diameters, and bent or straight bars. Steel fabric which is sold by the roll or sheet should be listed by size of mesh and weight per square foot, with the number of square feet given.

Masonry

To estimate the number of bricks required for a wall, the number of bricks per square foot of wall surface or the number of bricks per cubic foot of wall may be estimated. Allowance should be made for openings. When the number of bricks per square foot of wall surface is the basis for the estimate of the number of bricks required for a wall, the total must be multiplied by the number of bricks thick the wall is, that is, if it is more than one brick thick.

Bricks range in size from 2 to 3 inches in thickness, 3¼ to 4½ inches in width, 7½ to 9 inches in length, and about 60 to 76 cubic inches in volume. The standard size is 2¼

by $3\frac{3}{4}$ by 8 inches, with a volume of 67.5 cubic inches, and 18 square inches on the face. The length may vary $\frac{1}{8}$ inch by $\frac{3}{16}$ inches, depending upon the burning. The thickness of the joints between bricks may vary from $\frac{3}{16}$ to $\frac{3}{4}$ inch, with from $\frac{1}{4}$ to $\frac{1}{2}$ inch the most common thicknesses.

Walls of common brick increase in thickness by 4 or $4\frac{1}{2}$ inches. A wall 13 inches thick does not require any more brick than one 12 inches thick, so that this variation need not be considered when estimates are being made. In the past, estimators figured common brickwork on the basis of 7 or $7\frac{1}{2}$ brick to a square foot of 4- or $4\frac{1}{2}$-inch wall, 14 or 15 brick to a square foot of 8- or 9-inch wall, and 21 or $22\frac{1}{2}$ brick to a square foot of 12- or 13-inch wall. This method is still used where an overrun of brick is not too important, but a closer approximation may be achieved by the following method.

A brick 8 inches long plus a vertical, or END, mortar joint of $\frac{1}{4}$ inch equals a total length of $8\frac{1}{4}$ inches. A brick $2\frac{1}{4}$ inches high, plus a horizontal, or BED, mortar joint of $\frac{1}{2}$ inch makes a brick course with a height of $2\frac{3}{4}$ inches. Eight and $\frac{1}{4}$ inches times $2\frac{3}{4}$ inches equals $22\frac{11}{16}$ square inches for the total area on the face of the wall. To find the number of bricks per square foot of wall, divide 144 by $22\frac{11}{16}$. The result, 6.35 or $6\frac{1}{3}$, is the number of brick per square foot of 4 inch or $4\frac{1}{2}$ inch wall. It is well to add $1\frac{1}{2}$ to 2 percent to the total estimate of the number of bricks required in order to allow for waste because of broken or faulty bricks.

Most mortar mixes include cement, lime, sand, and water. The mortar required for a structure of brick or stone varies widely, depending on the size of the brick or stone, the thickness of the joints, and the proportions of the mix. A quantity estimate at best will be only approximate. The following table, prepared by the Quality Lime Institute, Philadelphia, Pa., gives a probable range of cubic yards of mortar required for one cubic yard of stone. The table is for various thicknesses of walls and of joints with no allowance for waste.

CUBIC FEET OF MORTAR REQUIRED PER THOUSAND BRICK

Joint thickness in inches	1″ wall	8″ wall	12″ wall	16″ wall	20″ wall	24″ wall
	cu. ft.	*cu. ft.*	*cu. ft.*	*cu. ft.*	*cu. ft.*	*cu. ft.*
⅛	2. 9	5. 6	6. 5	7. 1	7. 3	7. 5
¼	5. 7	8. 7	9. 7	10. 2	10. 5	10. 7
⅜	8. 7	11. 8	12. 9	13. 4	13. 7	14. 0
½	11. 7	15. 0	16. 2	16. 8	17. 1	17. 3
⅝	14. 8	18. 3	19. 5	20. 1	20. 5	20. 7
¾	17. 9	21. 7	23. 0	23. 6	24. 0	24. 2
⅞	21. 1	25. 1	26. 5	27. 1	27. 5	27. 8
1	24. 4	28. 6	30. 1	30. 8	31. 2	31. 5

Concrete blocks vary from 4 to 12 inches in height, from 6 to 12 inches in thickness, and from 12 to 32 inches in length. The most common size, sometimes called 8 by 8 by 16, is actually 7¾ inches high, 8 inches thick, and 15¾ inches long, and varies in weight from 50 to 60 pounds each. Besides the regular blocks, there are half blocks, jamb blocks, and corner blocks. Concrete tile, usually hollow, varies in height from 3 to 12 inches, and in width from 3¾ to 12 inches, with a 12-inch length. Concrete brick are usually made standard size and are rarely hollow. The face of a gypsum block or tile is usually 12 by 30 inches, and it may vary from 2 to 8 inches, or even more, in thickness.

Rubble and squared stone masonry are measured by the cubic yard or foot, or by the PERCH. A perch of stone contains 24¾ cubic feet, except in certain states, chiefly west of the Mississippi, where a perch is considered to contain 16½ cubic feet. Cut stonework is measured by the cubic foot; stone trim by the cubic foot; and stone veneer by square foot of surface with the thickness given, or by cubic foot. The amount of mortar used will vary greatly depending on the stone. The materials in the mortar mix are cement, lime, sand, and such special ingredients as are required, and are usually given by volume.

Roofing

Roofing is generally estimated by a unit of 100 square feet which is called a SQUARE. In shingling, the estimate may be based on the bundle or on 1,000 shingles. The area covered by a given number of shingles will vary as much as 40 percent, depending on the lap and spacing. Flashing may be given by the piece, by square foot, or by lineal foot; trim by lineal foot. Other materials used, besides the surface roofing materials, include nails and roofing paper and felt, downspouts, and gutters. Eaves flashing is measured by the lineal foot, but the price is determined by the amount of metal constituting a lineal foot and in terms of the weight of the metal.

Plumbing

Your estimate of materials for a plumbing job may consist of merely taking off the required materials from complete and detailed plans and specifications, or you may have to work from a schematic diagram. In the later case, you will have to depend on your knowledge of plumbing and a familiarity with local and Navy plumbing codes.

Plumbing is usually divided into two classes—rough plumbing and finish plumbing. Rough plumbing consists of:

1. PIPING.—Water, gas, and sewer pipes, both exterior and interior, including drains, soil and vent stacks, and soil, waste, and vent pipes.
2. All types of fittings, including valves, traps, unions, and nipples.
3. Packing and calking materials.
4. Hangers and other auxiliaries necessary for proper support and installation.

Finish plumbing includes all plumbing fixtures, such as showers, bath tubs with accessories, sinks, water closets, and stoves, water heaters, and drinking fountains when these are specified.

Heating and Air Conditioning

Heating systems may be classified as warm-air heating, steam heating, or hot water heating; and the takeoff for all three may include, as main headings, the following:

1. Heat-generating units.
2. Heat-distributing units.
3. Heat-control system.
4. Heat-conveying system.
5. Accessories.

Air-conditioning systems may be of the central or of the unit type. When an air-conditioning system is combined with a heating system, the two are often taken off together. If they are taken off separately, care must be taken to avoid duplication of items.

Electrical Work

As in the case of plumbing, the plans from which you work in making the electrical wiring estimate may vary in the amount of detailed information given. Electrical work, like plumbing, is divided into rough and finished work. The rough work consists of conduit and wiring, and it is installed as the building is erected. Finished electrical work consists of the electrical fixtures which are installed when the building is nearing completion.

Rough electrical materials include conduit, fittings, wire, outlet boxes, cutout boxes, switches, receptacles, fuse boxes, main switches, meter boards, panel boards, main switch and fuse boxes, and of knobs, tubes, and nails if open wiring is used. There may also be bells, buzzers, bell transformers, and, in some jobs, large panel boards, motors, motor generators, electric heaters, and other electrical machinery. Finished electrical materials include ceiling fixtures, wall brackets and fixtures, service switches and plates, and floor-and-wall-receptacles, plates, and push buttons.

In making takeoffs of the materials, it is best to work from the plans and specifications in a systematic manner. Some prefer to list all the materials one floor at a time and one

room at a time on each floor. If you work in this manner, be sure not to forget vertical wiring between floors. Others prefer to list materials by circuits, tracing one circuit from the main switch box and then a second circuit, and so on. With either method, you must remember to estimate the length of wires with adequate allowance for connections. The leads from the outside lines or from transformers should be included in the estimate as an extra item.

QUIZ

1. Where are statements concerning the quality of materials, workmanship, inspections, tests, guarantees, etc., concerning a designed structure made?
2. Why are the scales of the drawings for structures given both as equations and as graphic scales?
3. What is the official identification number of any item of Navy material?
4. What do the letters G, Y, or C indicate when they appear at the beginning of a stock number?
5. What do architectural specifications contain?
6. What is the first step in preparing a bill of material?
7. What is a takeoff?
8. Why are the unit terms in which the quantities of an item are expressed important?
9. What term for quantity is used in listing steel for floating structures?
10. What term is used in listing lumber?
11. What are the measurements of one board foot?
12. How does dressed lumber vary from the nominal size?
13. In what quantity terms are the nails for wooden construction estimated?
14. What materials are used in concrete construction?
15. How is concrete measured?
16. How are the proportions of a concrete mix usually expressed?
17. What causes concrete to harden?
18. How is the quantity of reinforcing steel listed?

19. How is the number of bricks required for a wall estimated?

20. What materials do most mortar mixes contain?

21. How are rubble and squared stone masonry measured?

22. What is the unit used in estimating roofing?

23. (a) What does rough plumbing consist of? (b) What does finished plumbing consist of?

24. Under what general headings can the materials for heating systems be included?

25. (a) What does rough electrical work consist of? (b) What does finished electrical work consist of?

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CHAPTER 11

SURVEYING, COMPUTING, AND PLOTTING

INTRODUCTION

Surveying is the science of determining the relative positions of points on the earth's surface. Distance, direction, and relative elevation of selected points are measured by the use of survey instruments in the field. The relative positions of the points measured can then be computed to the necessary degree of accuracy. Distance and height are measured in units of length, and direction is measured in units of arc.

The earth is a spheroid, not exactly a sphere, with the polar diameter about 27 miles less than the equatorial diameter. The curvature of the earth's surface is very similar to that of a sphere. The basic difference between PLANE and GEODETIC surveys can be expressed in terms of this curvature. In plane surveys, north-south lines on the earth are considered to be parallel, and east-west lines are considered parallel, while in geodetic surveys, the convergence of lines is taken into account. Both classifications involve the same types of ground measurement, made by the same basic methods, and there are no basic differences in the field operations. The distances between survey stations are often much greater in geodetic surveys, and special equipment, more precise instruments, and more precise procedures are usually required.

In geodetic surveys, the computations take into account the effect of the earth's curvature on the relative positions of the points connected by the survey. These positions are expressed as LATITUDES (angular values north or south of the Equator) and LONGITUDES (angular values east or west of the Greenwich meridian), or they are expressed as EASTINGS and

NORTHINGS on a rectangular-grid system that is based on true north. (See chapter 13.) Geodetic surveys usually cover large areas such as a state, a nation, or a continent, but the area may sometimes be quite small.

In plane surveys, the relative horizontal positions of the survey stations are computed with respect to a plane rectangular-grid system that may or may not be tied into a worldwide system of geodetic coordinates. Sometimes the effects of the earth's curvature may require limited consideration. For example, in a long traverse survey, it is customary to determine an astronomic azimuth at intervals of several miles along the traverse. Then, to check the measured values of the traverse angles between adjacent astronomic azimuth stations, the convergence of the meridians must be considered by adjusting the survey azimuth. This becomes the problem of how far plane coordinates may be carried from the origin. This distance depends on the accuracy desired. The errors of approximation in computing plane coordinates in small Navy project areas are of little or no consequence. But when the coordinates are extended over larger areas, the errors of approximation increase rapidly. The accuracy of the position in a 33⅓ mile square figure would be about 1 part in 25,000.

The methods used in making the survey and the way in which the notes are recorded depend on the purpose of the survey. The types you are most likely to come in contact with are:

1. CONSTRUCTION SURVEYS, which are made at sites where construction of an engineering nature is to be undertaken.
2. TOPOGRAPHIC SURVEYS, which are made to determine the shape of the ground, both horizontally and vertically, and the location of natural and cultural, or artificial, features.
3. HYDROGRAPHIC SURVEYS, which are made to determine the shape of the bottom of lakes, rivers, harbors, and oceans.

For more detailed discussions of the surveying methods mentioned in this chapter, read *Surveyor 3 & 2*, NavPers 10632–A, or *Elements of Surveying*, TM 5–232, published by the Department of the Army. For tables and formulas involved in surveying computations, refer to a standard civil engineering handbook.

Field Notes

Survey notes are usually entered in a bound, pocket-size notebook. When transit notes are recorded, tabulations of distances and angles are entered on the left-hand page, and it usually provides enough space for all level notes. The right hand page is often a sheet of graph paper with a red centerline running vertically down the page, and it is used for transit sketches and level profiles. (See fig. 11–1.)

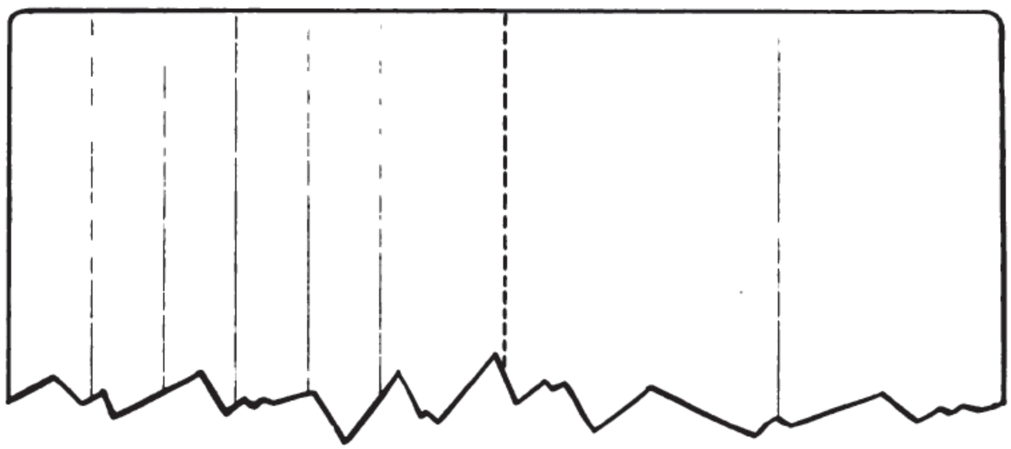


Figure 11–1.—Top portion of facing pages in a standard field book.

Level notes and notes for closed traverses are usually started at the top of the page. Notes for route surveys are started at the bottom and entered consecutively upwards, so that the positions on the sketch on the right-hand page appear in their appropriate places as the recorder walks forward along the line of the route.

In the United States, the foot is used by surveyors and civil engineers as a basis for field measurements. Fractions of a foot are expressed decimally, the nearest 0.01 of a foot should not be exceeded in third order surveys. Approxima-

tions like 0.10 should be confined to stadia surveys and the like. The term STATION was originally applied only to the actual point indicated by the numbered stake, but it is now universal practice in this country to use the word in referring to either the point or the 100-foot unit distance.

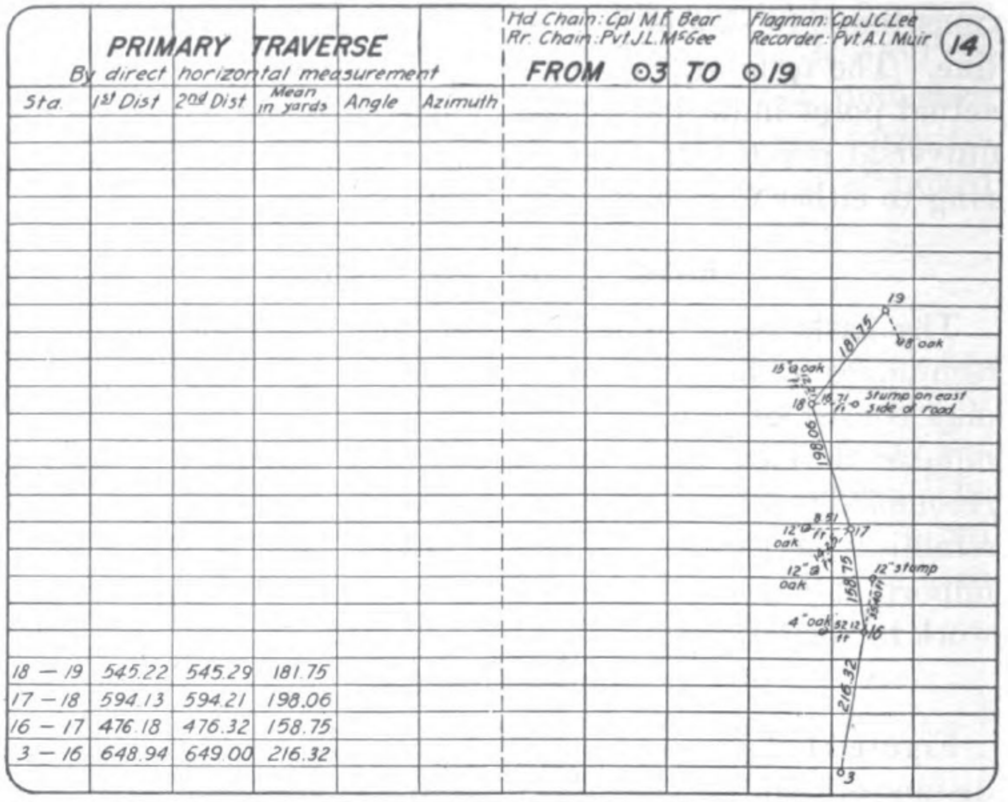
BASIC FIELD PROCEDURES

The basic field procedures used in surveying consist of techniques for measuring distances and angles. A field party may consist of only two men, or it may be made up of a number of men, each with a different function. Often a reconnaissance precedes the survey proper. Its purpose is to establish the general lay of the land. This is particularly important when the survey is to be made for construction work of some type.

Taping Distances

Figure 11–2 shows a method of recording taped, or chained, distances. In this case, each course was measured twice, the first measurement entered in the second column, and the second measurement in the third column of the field notes. In the fourth column, the mean of the two measurements was entered in yards (used with the polyconic projection) to the nearest hundredth. The unused columns headed ANGLE and AZIMUTH are to be used by the party which observes the horizontal angles. The right half of the right-hand page of notes shows a diagram indicating the location of each traverse station and its witness marks with all distances indicated. This procedure would apply to a first or second order traverse rather than to a routine survey, which would have the distances recorded in feet, rather than yards.

When a long survey line is to be measured with tape, it is first marked with range poles. The head chainman then sets 1 marking pin at the starting point, counts to be sure that he has 10 more, and starts out toward the first range pole, carrying the end of the 100-foot tape in his hand. The rear chainman allows the tape to pass through his hands in order to straighten any kinks, and calls halt just before the whole



PRIMARY TRAVERSE
By direct horizontal measurement

Hd Chain: Cpl M.F. Bear
Rr. Chain: Pvt J.L. McGee
Flagman: Cpl J.C. Lee
Recorder: Pvt A.I. Muir
14

FROM ⊙3 TO ⊙19

Sta.	1st Dist	2nd Dist	Mean in yards	Angle	Azimuth
18 — 19	545.22	545.29	181.75		
17 — 18	594.13	594.21	198.06		
16 — 17	476.18	476.32	158.75		
3 — 16	648.94	649.00	216.32		

Figure 11–2.—Record of taped distances.

length is drawn out. Then the head chainman turns, straightens the tape on the line under the direction of the rear chainman, and the tape is held taut and straight and horizontal from the top of the first pin, while the head chainman sets the second pin.

The rear chainman then pulls the first pin, and they repeat this procedure until the head chainman has set his tenth pin and the rear chainman has 10 pins in his hand. These 10 pins he gives to the head chainman, and they continue as before. When the head chainman reaches the end of the line, he sets the pin, next carries the tape ahead, and then steps back and reads the fraction at the pin, recording the total distance (number of tape lengths plus the fraction) in the field book.

When measurements are made on a slope, there are two ways of getting the horizontal distance. The measurement may be made along the slope and then corrected by convert-

ing the slope to the horizontal distance by computation, or it may be made by what is called BREAKING TAPE. In this case, the tape is held level or horizontal over as great a distance as possible. Then the high point of the tape is transferred to the ground by a plumb-bob line. This method of measuring on a slope is best and is used whenever possible.

Stadia Measurements

Stadia measurements are read on a rod with a telescopic instrument such as an engineer's transit. An intercepted interval, known as the STADIA INTERCEPT or STADIA INTERVAL, between the upper and lower horizontal lines (stadia hairs) of the telescope's reticle is read on the rod which is held vertically at some distance from the observing instrument. The value of a stadia intercept is directly proportional to the distance between the observing instrument and the rod.

When the line of sight of the instrument is inclined upward or downward, the value of the vertical angle becomes one of the factors necessary to reduce stadia readings to horizontal distances. (See fig. 11–3.) The stadia formulas

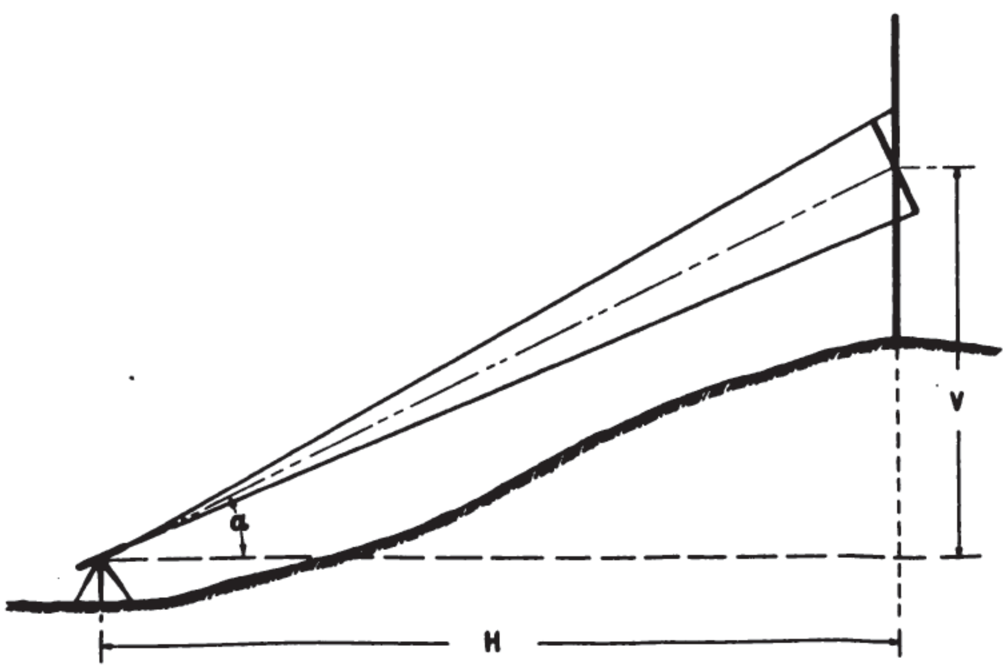


Figure 11–3.—Inclined stadia observation.

to determine the horizontal distance, D, and the difference of elevation, DE, from the stadia intercept, I, and the vertical angle, are as follows:

$$D=\frac{f}{i} I \cos^2 \theta + C \cos \theta,$$

$$DE=\frac{f}{i} I \tfrac{1}{2} \sin 2 \theta + C \sin \theta,$$

in which $\frac{f}{i}$ is the stadia interval factor (which can be assumed to be 100) and C is the stadia constant for the instrument.

The stadia constant, C or $(f + c)$, is equal to the focal length of the telescope's objective lens, f, plus the distance from the objective lens to the center of the instrument, c. Ordinarily, this value is determined by the manufacturer and is noted on the inside of the instrument carrying case. For normal stadia work, the constant C is assumed to be zero for the internal focusing type of instrument and 1.0 foot for the external focusing type of instrument.

Measurements of Horizontal Angles

A direction, in surveying, refers to the angular relationship of one line to another. Horizontal directions are designated as being either clockwise or counterclockwise from a base or zero direction. In surveying, all horizontal angles for directions are considered as being clockwise unless designated in some manner as being counterclockwise. Multiple horizontal angular readings should not be necessary on routine third order surveys, but they are necessary on second or first order surveys where the probable error of main scheme angles is 3 seconds.

The angles of a traverse may be measured by several methods. The interior angles, illustrated in figure 11–4A, may be given, or the deflection angles, illustrated in figure 11–4B. A deflection angle consists of the angle between one course produced, or extended, and the next course. Deflection angles may be either right (R) or left (L) and are so designated in the notes. The exterior angles of the traverse,

illustrated in figure 11–4C, may be measured, and these angles are always given one after the other in clockwise order around the traverse. In place of any of these methods, the azimuths of the courses, illustrated in figure 11–4D, may be recorded in the notes.

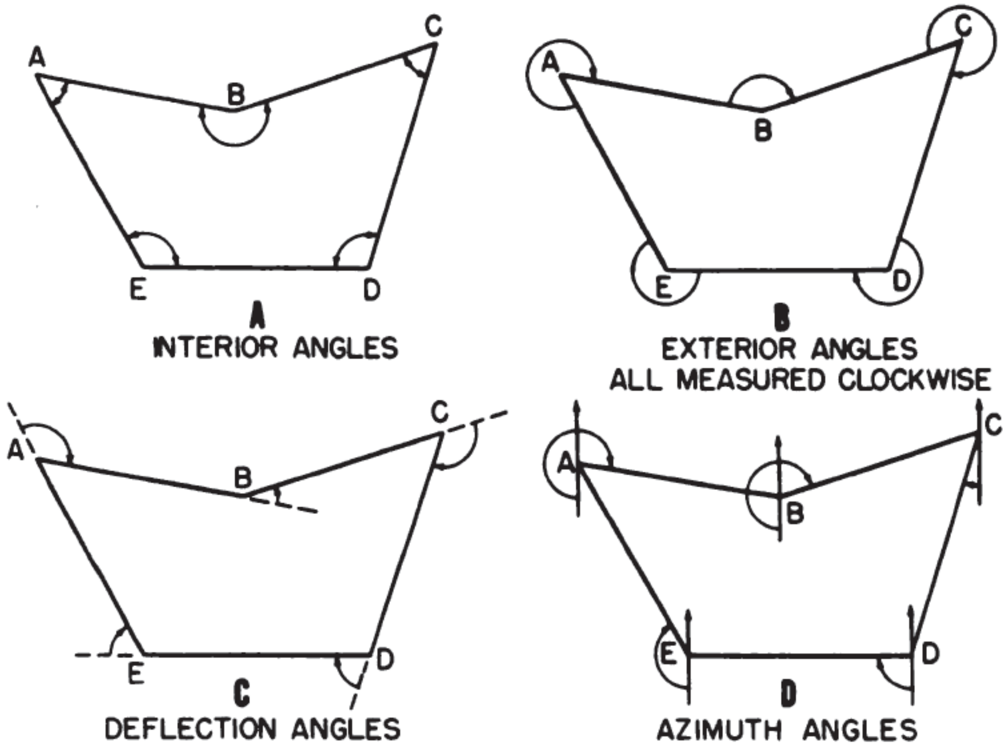


Figure 11–4.—A. Interior angles. B. Exterior angles, measured clockwise. C. Deflection angles. D. Azimuth angles.

Azimuth is measured clockwise from a zero line running north and south. Every line has two azimuths, the forward and the back azimuth, which differ by 180 degrees. A true azimuth of any line is its horizontal direction from true north. A grid azimuth of a line is its horizontal direction from a grid line which may coincide with a true north-south line or may be roughly parallel to such a line. Magnetic azimuths are measured with magnetic north as the line of zero azimuth.

The bearing of a line is its direction within a quadrant with reference to a meridian. Bearings are measured clockwise and counterclockwise, depending on the quadrant, from

either north or south. A bearing is identified by naming the end of the meridian from which it is reckoned, and the direction (east or west) from that meridian. Thus, a line in the southwest quadrant making an angle of 30° with the reference meridian (south) will have a bearing of S 30° W. Bearings, like azimuths, can be true, grid, or magnetic. The relationship between bearings and azimuths is shown in figure 11–5.

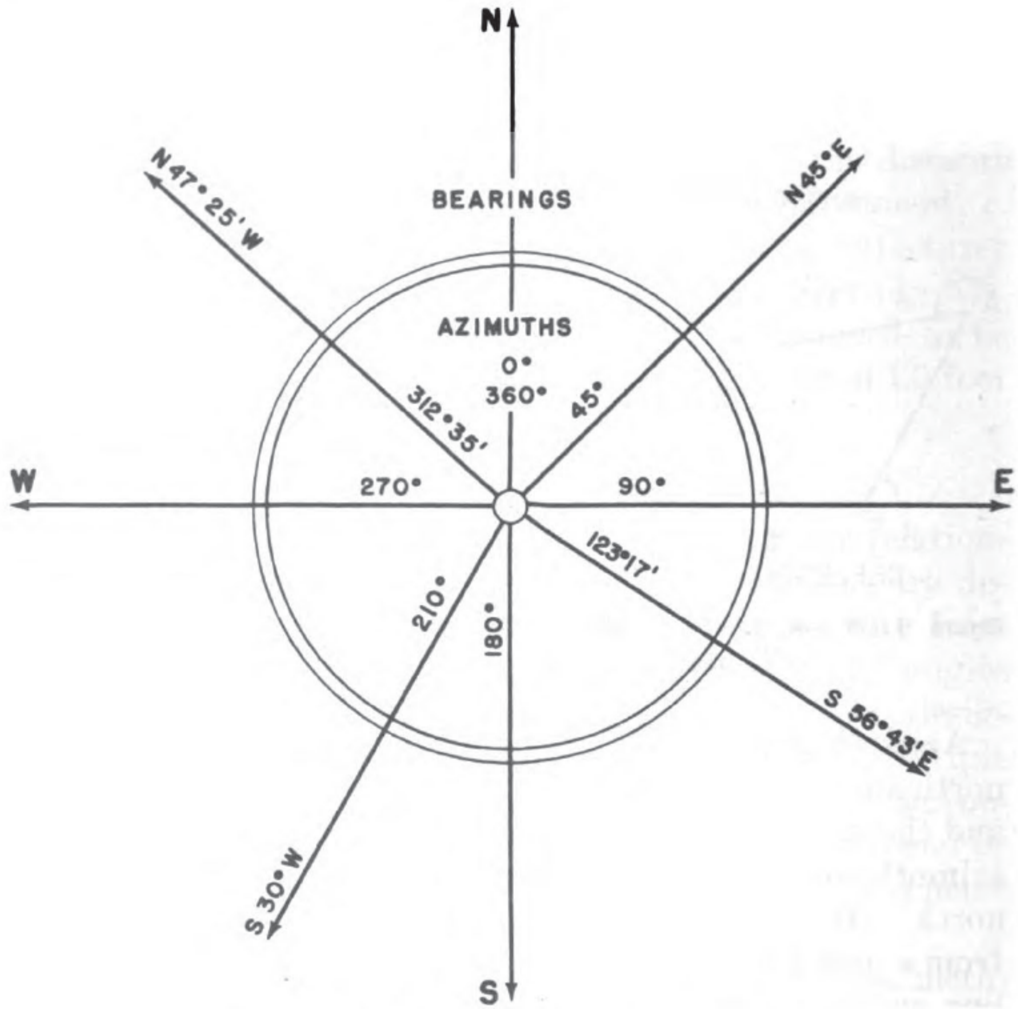


Figure 11–5.—Relation of bearing to azimuths.

The meridian indicated by the needle of a magnetic compass will seldom coincide with the true meridian. The horizontal angle between the magnetic meridian and the true meridian, at a point, is called MAGNETIC DECLINATION. When

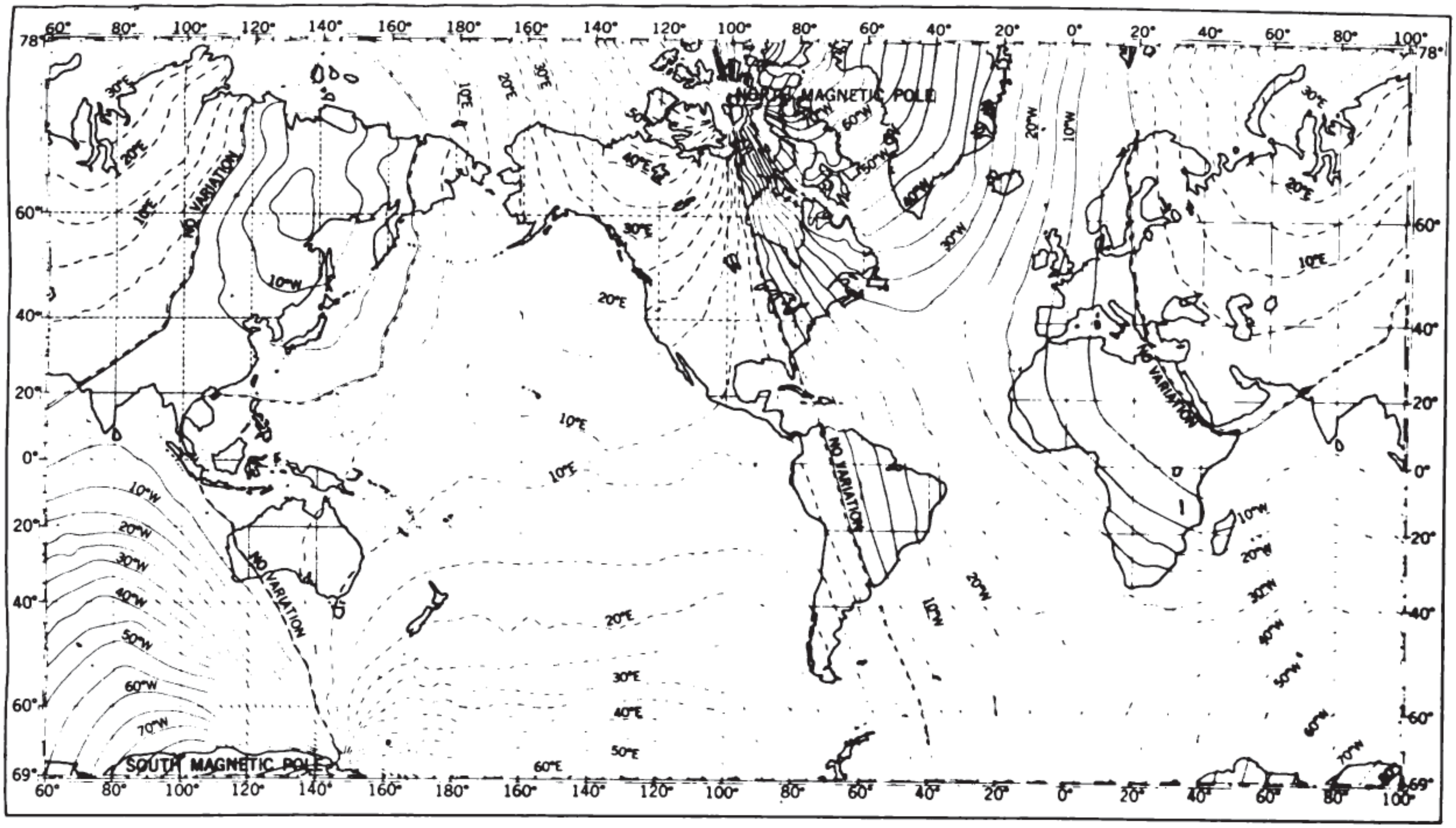


Figure 11–6.—Isogonic chart.

the magnetic needle points eastward of true north, the magnetic declination is east, and when the needle points westward of true north, the magnetic declination is west. The magnetic declination at any point is not a constant value, but is continually changing.

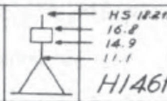
When the magnetic declination is east, its angular value added to the magnetic azimuth of a line gives the true azimuth of the line. When the magnetic declination is west, its angular value subtracted from the magnetic azimuth of a line gives the true azimuth of the line. Because of the variation in the magnetic declination, true azimuths determined this way cannot be relied on closer than to about one-fourth degree of arc.

A chart with lines joining all places where the magnetic declination is the same at any instant is called an ISOGONIC chart. Such charts for the United States are published every 5 years by the United States Coast and Geodetic Survey. The solid lines on the isogonic chart are lines of equal magnetic declination, and every point along one of these lines has the same magnetic declination. (See fig. 11–6.) These lines are drawn for each degree of declination, both east and west of zero. The line representing zero degrees declination is known as the AGONIC line. Lines to the east of the agonic line indicate west declinations, and those west of the agonic line indicate east declinations.

A value for a horizontal angle between any 2 lines can be determined by pointing at a target on 1 of the lines, pointing at a target on the other line, reading the horizontal circle on the instrument for each pointing, and finding the difference between the 2 readings. Because the angular value determined in this manner is subject to the effect of numerous errors, all angles should be measured at least twice, once with the instrument direct and once with the instrument plunged. A greater number of measurements are often made to obtain a mean value with a minimum of residual error.

There are two basic methods for the multiple measure-

Horizontal Angles
State: Ohio County: Clarke
At △ Knoll



Obs: T. Sgt. J. Doe
Rec: Cpl. T. Cane
Inst: 10" K & E 60606

18 April 1940
Cloudy and cool
15 Mile wind

④

Objects observed	Tel.	Rep	Readings	A	B	Mean	Mean of 6		Set Mean	Hor. Adj.	Remarks
△ Shoulder	D	0	0° 00'	00	10	05"					10:35 AM
△ Knob		1	30 15	30							
		6	181 32	40	50	45	30° 15'	26.7"			
	R	6	359 59	50	00	59 55		28.3	27.5	26.6	30° 15' 26.6"
△ Knob	R	0	00 00	20	30	25					10:55 AM
△ Top		1	82 41	00							
		6	136 06	30	40	35	82 41	01.7			
	D	6	0 00	40	40	40	40	59.2	41 00.4	40 59.5	82° 40' 59.5"
△ Top	D	0	0 00	25	30	27.5					11:10 AM
△ Shoulder		1	247 03	40							
		6	42 21	50	60	55	247 03	34.6			
	R	6	0 00	20	30	25		35.0	34.8	33.9	247° 03' 33.9"

Figure 11–7.—Sample field notes for six repetitions.

ment of a horizontal angle: the repetition method and the direction method. The repetition method is normally used with a repeating instrument, such as a transit. The direction method can be used with any transit or theodolite.

With the repetition method, the angle is measured, and then, without turning the telescope back, it is measured again and again as many times as may be desired. The total in degrees is then divided by the number of times the angle was measured in order to arrive at the angle measurement. A set of observations may consist of 2, 3, or 6 repetitions of the angle with the telescope in the direct (or reversed) position, followed immediately by 2, 3, or 6 repetitions of the explement (that is, the remainder of the 360° in a circle) of the angle with the telescope in the reversed (or direct) position. Figure 11–7 illustrates a set of 6 repetitions, 6 direct and 6 reverse. Notes for 2 and 3 repetitions are kept in the same form.

Note that an initial direct reading of the angle between the △ Shoulder and the △ Knob is entered on the second line of the notes with the figure 1 under the heading Rep (repetitions). This reading is 30°15′30″. The angle is then repeated 5 times and the total reading entered on the line with the figure 6 under Rep. On the same line, the mean of the six readings is entered. The angle is then repeated 6 times with the telescope in reverse, and the mean of the 6 readings entered. The final mean of the direct readings and the reverse readings is entered under the heading Remarks. On routine surveys, two repetitions from the B. S. to the F. S. are made, the first with the telescope erect and the second with it reversed.

Leveling

The purpose of leveling is to determine the difference in elevation between points or to determine the elevation at any given point. Direct leveling uses the leveling instrument and one or more leveling rods for the direct measurement of vertical distances. It is the most accurate method of determining elevations above a datum plane. Differential leveling is the method of direct leveling used to determine differences in elevation. Trigonometric leveling is an indirect method in which the elevation is computed by using trigonometry.

Altimeter leveling determines approximate differences in elevation between points by measuring the atmospheric pressure at these points. The instrument, called an altimeter, is an aneroid barometer graduated in feet. Changes in atmospheric pressure cause movement of the thin, corrugated metal top of a partially exhausted metal box. In some altimeters a thin-walled, curved, metal tube changes its curvature. Since these instruments can be used only for approximate measurements of differences in elevation, altimeter leveling is used principally in topographic surveys where many spot elevations are required.

Bench marks are fixed points of known elevations. A

bench-mark system, or level net, consists of bench marks established at intervals along closed circuits over which level lines have been run. The elevations of all bench marks in a system are determined from the same level datum. Within the United States, bench marks usually refer to a MEAN SEA-LEVEL DATUM.

The procedure of DIFFERENTIAL LEVELING is shown in figure 11–8. The leveling instrument is set up and leveled at each of the indicated positions. At each setup of the instrument, a BACKSIGHT and a FORESIGHT rod reading are made, while the rod is held on either a bench mark or a TURNING POINT. A backsight is taken on a known point of elevation, and a foresight is taken to determine an elevation. A turning point is any convenient point for determining an elevation that is not a bench mark.

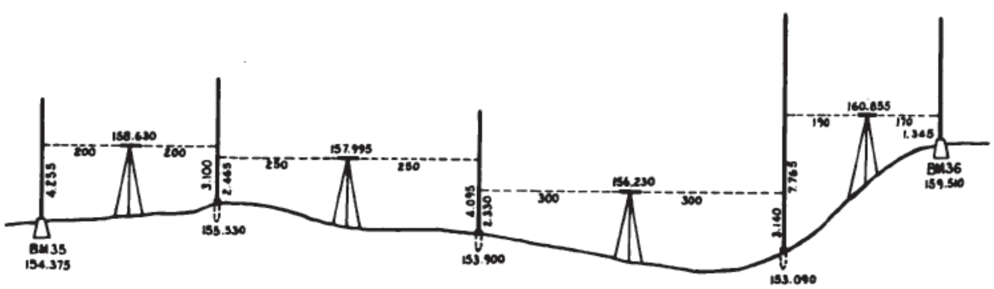


Figure 11–8.—Differential leveling.

With the leveling instrument, usually only the middle horizontal cross hair is used for making each backsight and foresight reading. Field notes for differential leveling by this method are shown in figure 11–9.

The values recorded in the columns headed BS and FS are respectively the backsight and foresight rod readings. The elevation (ELEV) of the first station (BM 35) has been previously established for this point. The values in the column headed HI (height of instrument) are determined by adding the BS value to the elevation of the point on which the rod was held for this backsight rod reading. The elevation of the second and successive stations is determined by subtracting the FS reading from HI value. For example,

		DIFFERENTIAL LEVELING BM 35 to BM 36				
STATION	BS	HI	FS	ELEV		
BM 35				154.375		Elev. & description from book L19, p. 32
	4.255	158.630			200	
TP			3.100	155.530	200	
	2.465	157.995			250	
TP			4.095	153.900	250	
	2.330	156.230			300	
TP			3.140	153.090	300	
	7.765	160.855			190	
BM 36			1.345	159.510	· 170	Elev & description entered in book L19, p 33
	16.815		11.680			
	11.680					
	5.135					
	154.375					
	159.510	✓				

Figure 11–9.—Sample field notes for differential leveling by one-hair observation.

the rod reading of the second point, 3.100, subtracted from the HI value of the first point, gives the elevation of the second point, 155.530.

The right-hand page of the notebook, which is always used to clarify the tabular notes on the left-hand page, contains cross references for the descriptions of the bench marks. Descriptions of any new bench marks would be entered here. Field notes were checked by adding the recorded values of all backsights and turning-point foresights. The difference between these two sums must equal the difference in elevation between the first and last recorded BM or TP elevations. Closures required for second order levels should be

$$0.035 \text{ foot } \sqrt{\text{miles run}}$$

and for third order,

$$0.05 \text{ foot } \sqrt{\text{miles run}}.$$

The extension of a level line across a wide river, ravine,

or similar obstacle involves backsight and foresight distances differing greatly in length. Ordinary differential leveling procedure may not give accurate results because of the variable effects of atmospheric refraction. Reciprocal leveling procedure to eliminate refraction error is illustrated in figure 11–10.

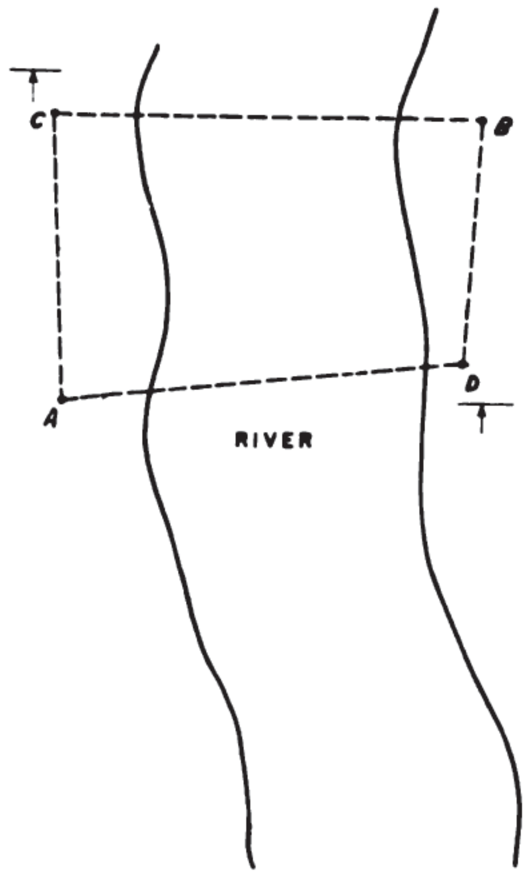


Figure 11–10.—Reciprocal leveling.

In the figure, A is a bench mark or turning point of known elevation. To determine an elevation for B, on the opposite side of the river or obstacle, the instrument is set up at a convenient point C and rod readings are taken on A and B. Next, a convenient point D is located for setting up the instrument so that BC approximately equals CA, and AD approximately equals CB. With the instrument on D, the difference in elevation between A and B is again determined. The differences in elevation between A and B as observed from C and D are then averaged to get the difference in elevation between A and B.

To measure a vertical clearance such as an underpass, the elevation of the bottom of the bridge stringers is determined by holding an inverted rod against the bottom of the overhead structure as shown in figure 11–11. The erect-rod reading plus the inverted-rod reading $(a + b)$ equals the vertical clearance between the two surfaces.

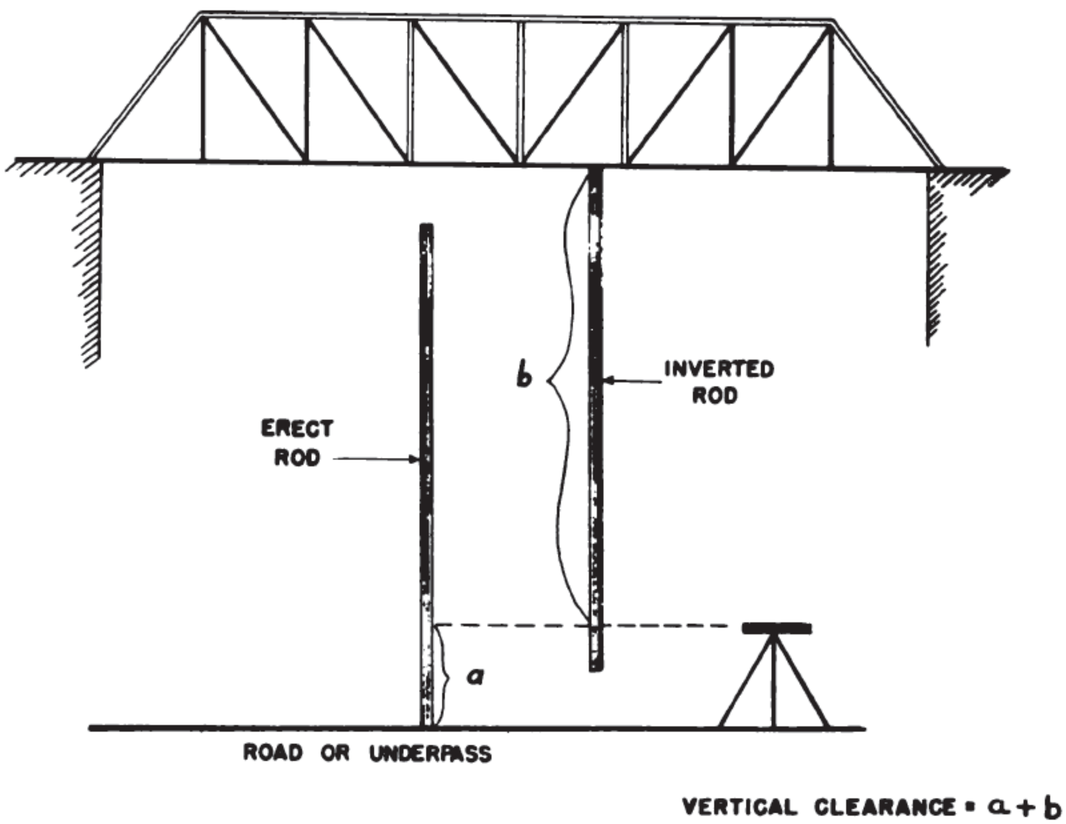


Figure 11–11.—Measuring vertical clearances.

Vertical angles are measured with either a transit or a theodolite. If a transit is used, the angles may be measured by the one-hair method or by the three-hair method. In the one-hair method, 2 pointings on the target are made, 1 with the telescope direct and 1 with it plunged, using the altitude clamp and tangent-screw to sight on the target with the horizontal cross hair. The vertical circle is read for each pointing and the mean of the readings is taken as the value of the vertical angle. The field notes for vertical-angle measurements should appear as shown in figure 11–12.

OBJECT OBS.	TEL.	VERT. CIRCLE		MEAN ALTITUDE		REMARKS
	⊼	AT STATION Wolf				
Fox	D	+3°	27'30"			
	R	3°	27'00"	+3°	27'15"	
Dog	D	+5°	42'00"			
	R	5°	41'30"	+5°	41'45"	
Coyote	D	−1°	18'00"			
	R	1°	18'30"	−1°	18'15"	

Figure 11–12.—Sample field notes for vertical-angle measurements with a transit.

In the three-hair method with the transit, the value of a vertical angle can be determined more accurately by making 3 direct and 3 reversed pointings on the target. Direct and reversed pointings are made with each of the three horizontal lines of the reticle. The vertical circle is read for each of these pointings and the mean of the six readings is then taken as the value of the vertical angle.

With a Wild T2 theodolite, pointings are made with the telescope both direct and reversed, as described for the transit. The vertical circle is read for each pointing and the mean vertical altitude value is determined.

TRIGONOMETRIC LEVELING applies the fundamentals of trigonometry in an indirect method of running level lines with a transit. Field procedure involves the measurement of vertical angles and slope distances. Trigonometric leveling determines elevations of low-order accuracy. It is particularly adaptable to uneven terrain where ordinary leveling

sights would necessarily be short and to situations such as reconnaissance and pipeline surveys where the time element is a prime consideration. Although trigonometric level lines can be run with an error of 0.2 foot per mile, side checks are made whenever possible to elevations of higher-order accuracy.

The sine method procedure is illustrated in figure 11–12. The distance of the telescope above the ground has been measured and found to be 5 feet. Therefore the 5-foot mark on the rod is used as the signaling point in order to develop the parallelogram $ABCD$ in figure 11–13. To determine the HI (height of instrument) from a point of known elevation for the situation shown in figure 11–13, measure the vertical angle α from the horizontal line of sight to the 5-foot marking on the rod. The slope distance DA or CB from the rod to the instrument is determined by taping or stadia. Since the rod, DC, equals 5.00 feet and AB equals 4 to 5 feet, which is the height of the instrument above ground, AD and BC are assumed to be equal and parallel. The vertical distance D to E is commonly called the difference in elevation and is referred to as the DE. The $\sin \alpha = \frac{DE}{AD}$ or $DE = AD \sin \alpha$. The HI then equals the ground elevation plus the rod (5-foot marking to which the vertical α was read) plus the computed DE.

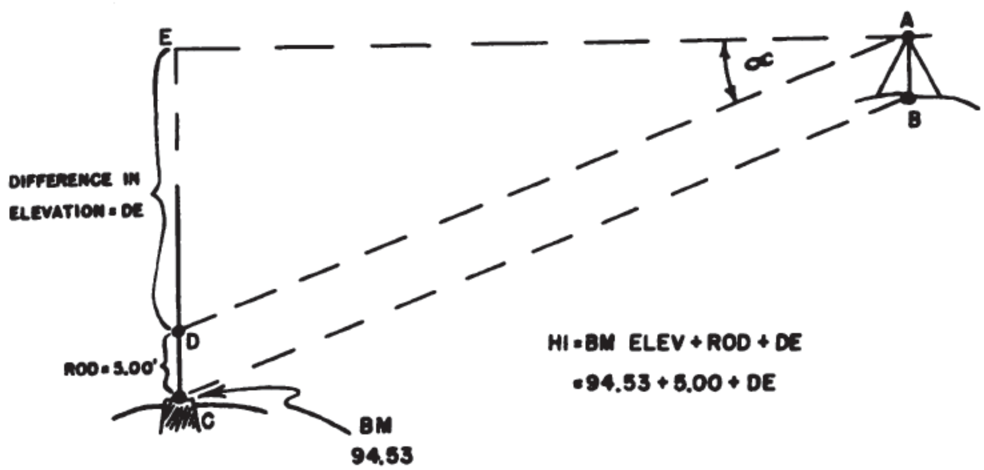


Figure 11–13.—Trigonometric level, depression angle backsight.

The procedures for a depression angle foresight, an elevation angle foresight, and an elevation angle backsight in trigonometric leveling are similar to the procedure for a depression angle backsight and are illustrated in figure 11–14.

A sample set of trigonometric level notes is shown in figure 11–15. The sample notes cover, in the same order, the four situations illustrated in figures 11–13 and 11–14. The recorder should denote whether the vertical angles are angles

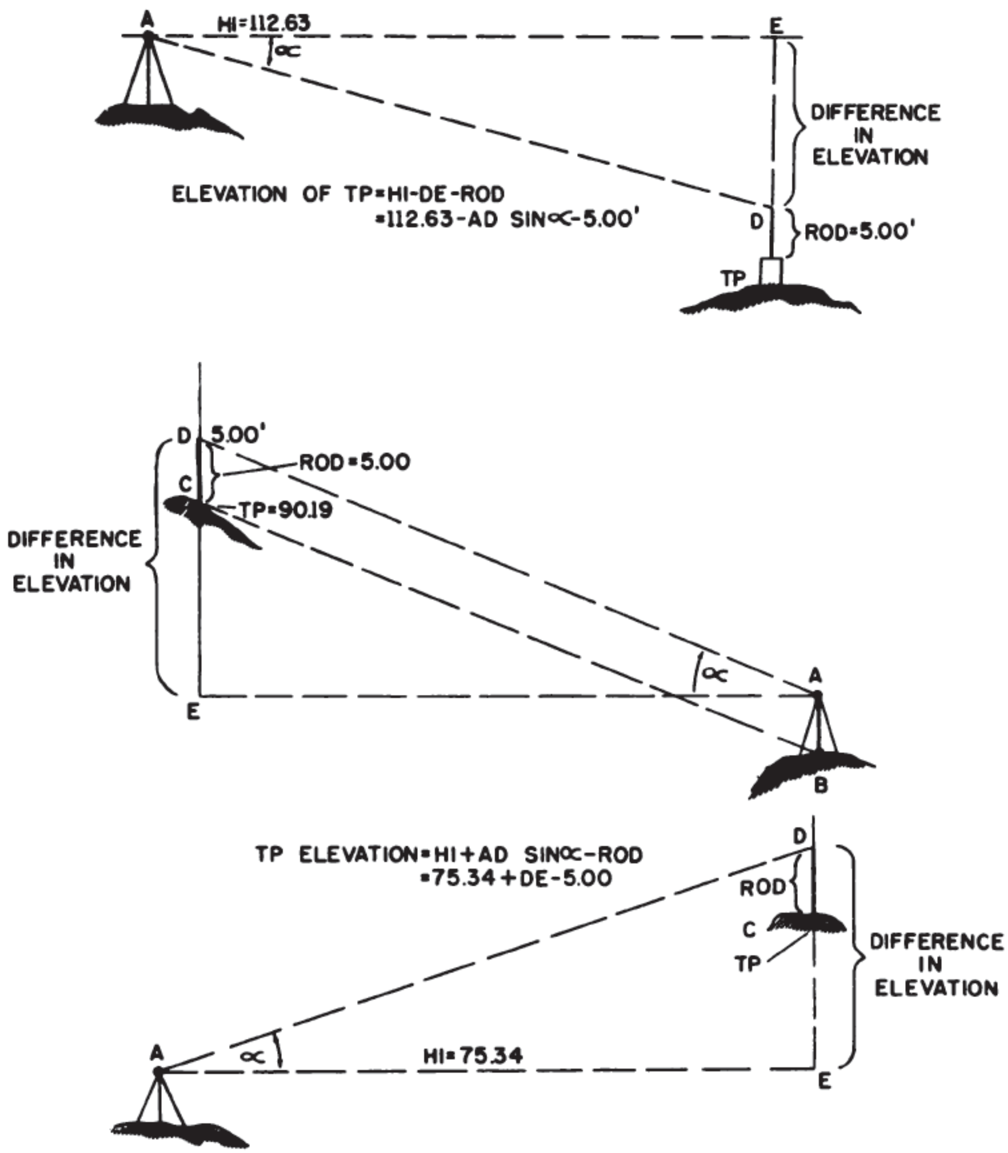


Figure 11–14.—Procedures for trigonometric leveling: A. Depression angle foresight. B. Elevation angle backsight. C. Elevation angle foresight.

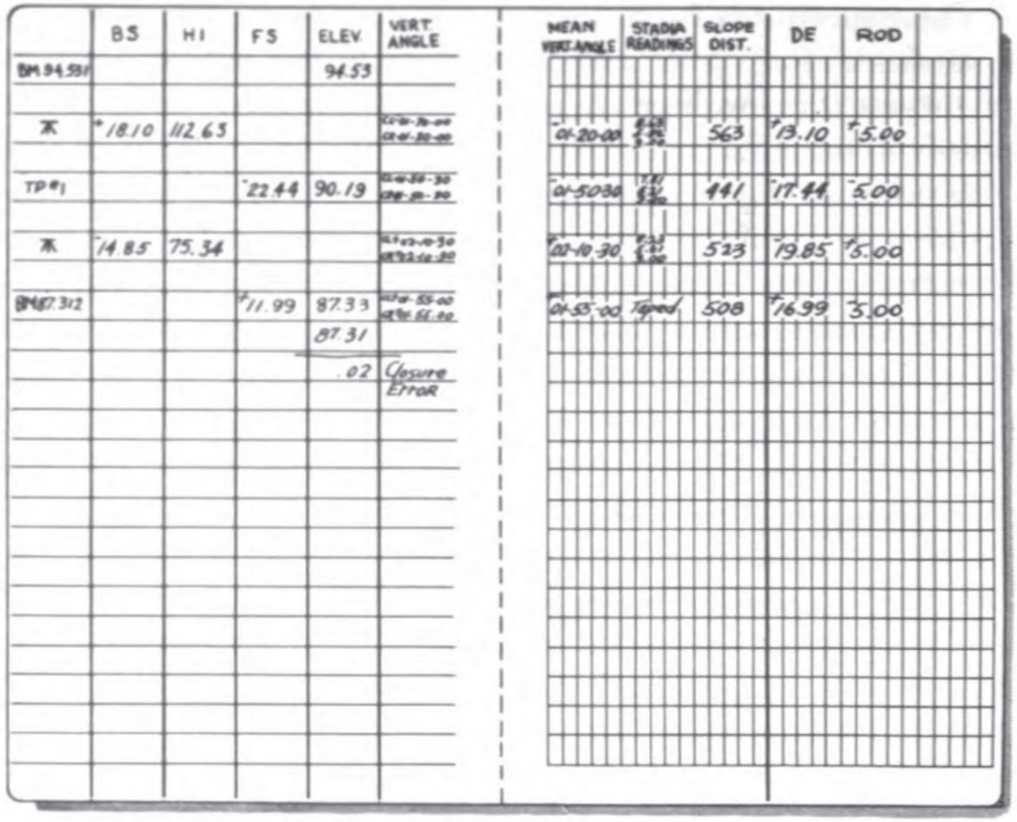


Figure 11–15.—Notes for a stadia, trigonometric level line.

of elevation (plus) or depression (minus). In computing backsights and foresights, the recorder gives the *DE* and *ROD* measurements with plus or minus signs. The computations of trigonometric level lines can be done by the recorder in the field, or it can be done in the office. If he records all three stadia hair readings, the recorder can check half-stadia distances for incorrect readings. If distances are taped, the column headed STADIA READING is usually omitted. A combination of stadia and taped distances is recorded as shown in figure 11–15 with a notation in the stadia-readings column indicating that the distance was taped.

The tangent method of trigonometric leveling involves the conversion of slope to horizontal distance. The product of horizontal distance and the tangent of the vertical angle (α) equals the difference in elevation (DE) in all four cases. Notes are recorded in some form similar to figure 11–15.

Traversing

In surveying, TRAVERSING is defined as the field operations of measuring the lengths and angles of a series of straight lines connecting a series of points on the earth. The points connected by the lines of a traverse are known as traverse stations, or as traverse-angle stations.

A traverse is always classified as either a CLOSED TRAVERSE or an OPEN TRAVERSE. It is also classified by the instruments used, such as a transit-tape traverse; by the quality of results obtained, such as a third-order traverse; and by the purpose served, such as a road-centerline location traverse.

A closed traverse starts and ends at the same point, or at points whose relative horizontal positions are known. A LOOP TRAVERSE forms a continuous loop enclosing an area. A CONNECTING TRAVERSE starts and ends at separate points whose relative positions have been determined by a survey of an equal or higher-order accuracy. A connecting traverse of third-order accuracy, for example, may be run and adjusted between two stations whose relative positions were determined by a first-, second-, or third-order traverse or triangulation.

An OPEN TRAVERSE ends at a station whose relative position is not previously known, and unlike a closed traverse provides no check against mistakes and large errors. An open traverse may start at a station of assumed position, but usually it starts at a station determined by a closed traverse or by triangulation. Such traverses are often used for the preliminary survey for a road or railroad. When the traverse is run for the centerline location, ties to the preliminary traverse form a series of closed, loop traverses.

A RANDOM TRAVERSE is a special adaptation of an open traverse. It is run between 2 stations to determine their relative positions, after which the traverse is usually closed by running in the computed line between the 2 points.

The procedures followed in making field and office computations are given in *Surveyor 3 & 2*, NavPers 10632–A.

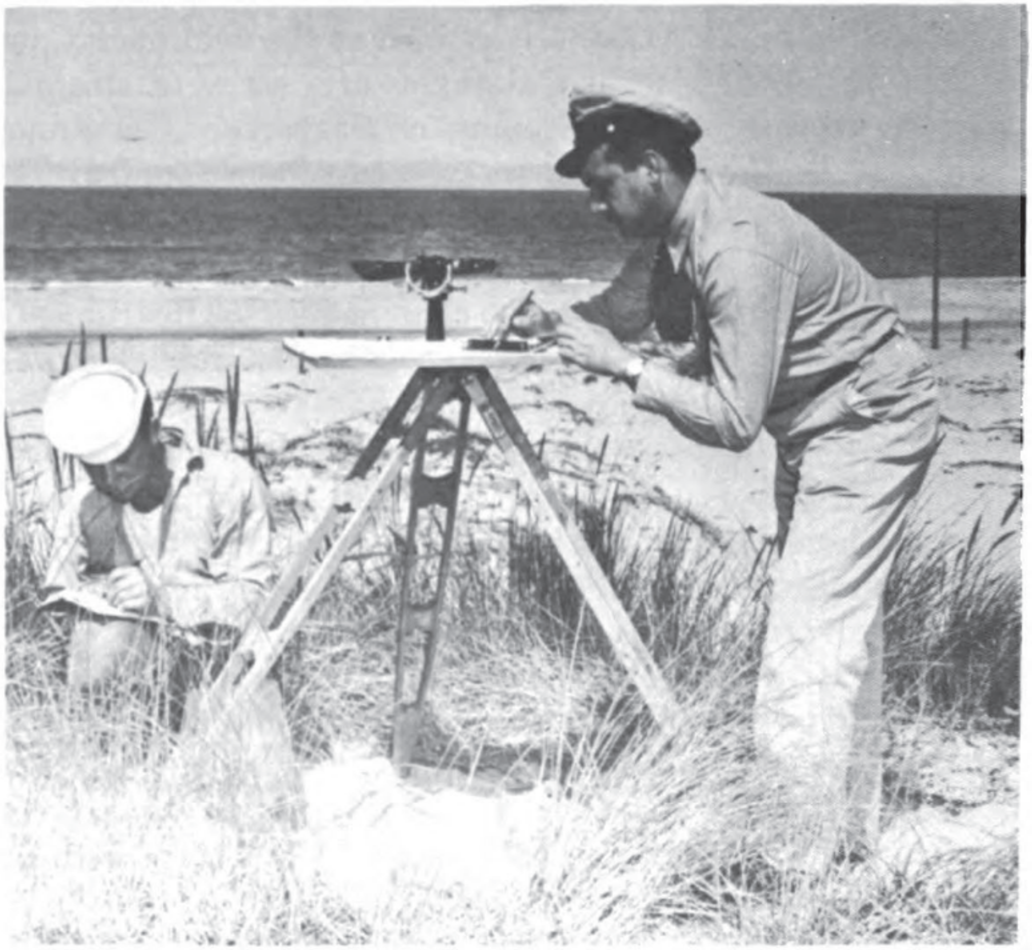


Figure 11–16.—A plane table and telescopic alidade.

Plane Table Surveying

A plane table is very effective as an instrument for surveying detail and topography accurately. It consists of a drawing board mounted on a tripod. Drawing paper is placed on this board and the map drawn in the field as the survey progresses. The board or table can be leveled and oriented and sights are taken by means of an instrument, called an alidade, on top of the table. (See fig. 11–16.)

The plane table is set up over a station and oriented so that the point on the map on the drawing board which corresponds to the station is theoretically vertically over the station. Thus lines on the drawing board from the station will be parallel to lines on the ground.

The plane table may be used to locate points by RADIATION, as shown in figure 11–17. The distances to the points are obtained by reading stadia rods or by taping, and then the points are plotted to scale along the corresponding rays on the map. A plane table is used in traversing between two control monuments or stations. In this case, it is set up on each succeeding station in turn, and the distance between stations obtained by stadia or taping.

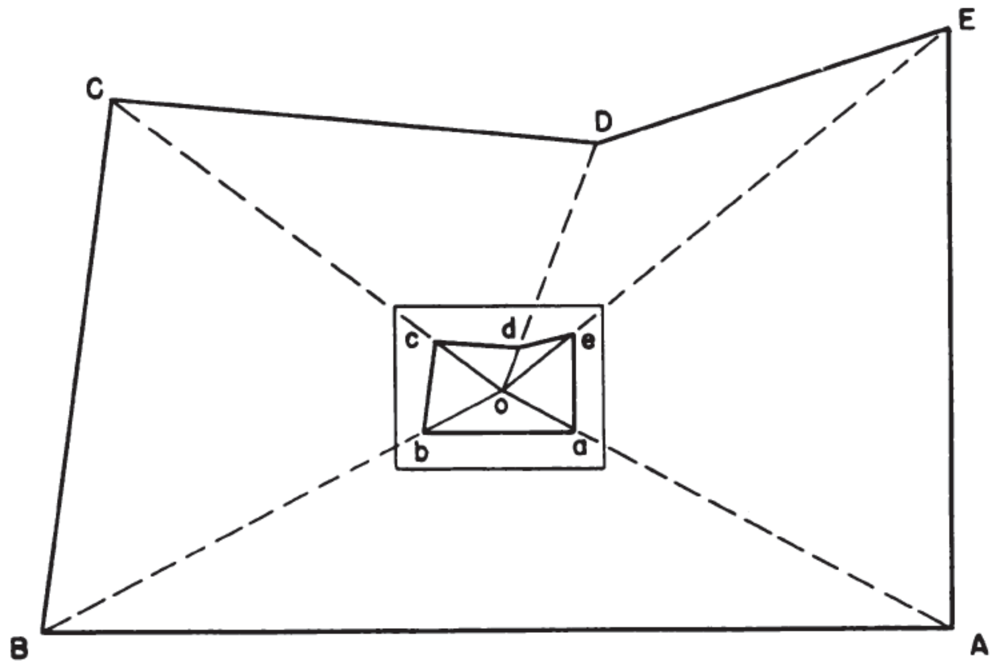


Figure 11–17.—Locating points by radiation.

If two points are known, a third point may be found by INTERSECTION. For example, in figure 11–18, the position of the two points A and B are known. To locate point X, the plane table is first set up at point A and oriented to point B. Then a ray is drawn on the board in line with the rod on X. Next the table is set up on B and oriented with A, and a second line is drawn from B to X. The intersection of this line with the first line, locates point X on the board.

Another method of locating points is by RESECTION. For this method, it is necessary that two points be known and plotted on the map. In the simplest example of resection, the way in which it varies from intersection can easily be

illustrated. For example, the two known points are A and B. The plane table is first set up on B and oriented on A. Then a sight is made on X and a line is drawn toward X. Next the plane table is set up on X, oriented on B, sighted on A, and a line drawn toward A. The intersection of this line with the line from B is the location of X on the map.

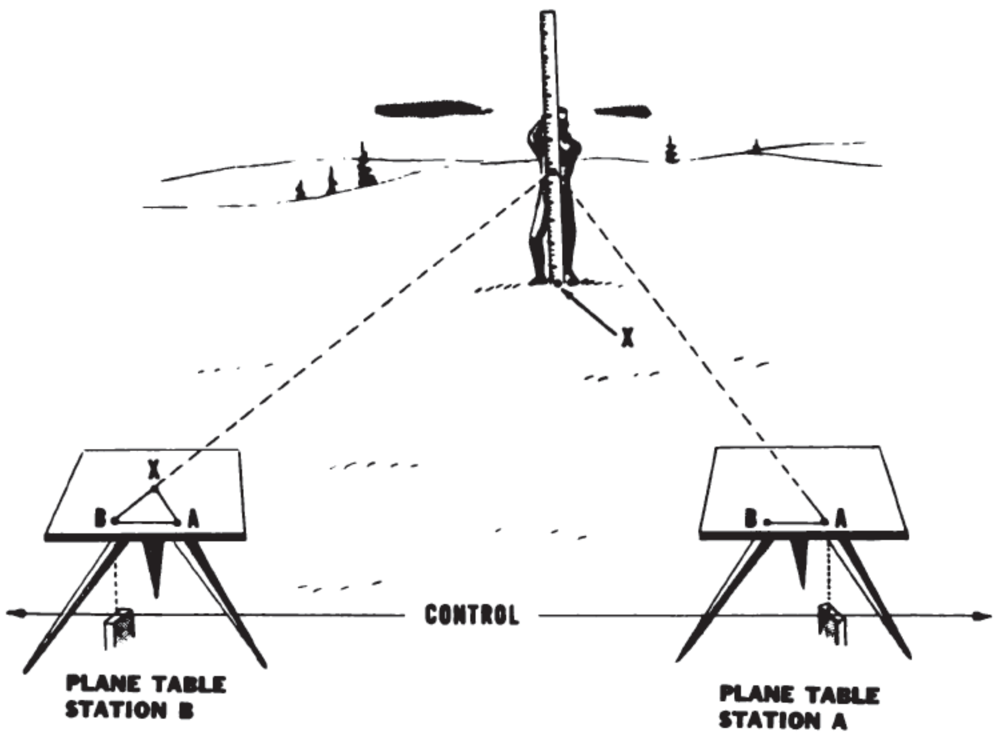


Figure 11–18.—Plane-table location by intersection.

PROFILES AND CROSS SECTIONS

A profile may be plotted from data obtained by field parties or from a large-scale contour map. Profiles are made for the centerline of roads and railroads which are to be constructed and for other construction projects or as a method for determining the intervisibility between two points on a map.

The profile is plotted on special paper, with the vertical scale exaggerated. In road and railroad profiles the scales used may be 400 feet to the inch horizontally and 30 feet to the inch vertically. A still greater exaggeration is generally used for drainage profiles.

Leveler: H.L. Chippeaux   Dumpy Level #12328
Rodman: C.F. Browning

(11)

PROFILE LEVELS FOR ROAD   FROM ⊙0+00 TO ℄11+00

Sta.	+B.S.	H.I.	−F.S.	Elev.	Elev. T.P.	Remarks: Nov. 16, 1939 (2¾ hours) Fair, windy
0+00	0.06	123.56			123.50	Wooden peg
0+00			0.4	123.2		
1+00			6.3	117.3		
T.P.	0.32	111.35	12.53		111.03	
2+00			5.4	106.0		
2+56			9.7	101.7		Center stream bed 5' wide 2½' deep
2+56	3.91	105.93	9.33		102.02	T.P.
3+00			4.5	101.4		
3+90			6.7	99.2		Center stream bed 5' wide 2½' deep
4+00			4.5	101.4		
4+27			2.7	103.2		Bottom steep slope
T.P.	13.00	118.51	0.42		105.51	
4+80			2.8	115.7		Top steep slope
5+00			1.2	117.3		
5+00	8.24	125.95	0.80		117.71	T.P.
6+00			4.8	121.2		
7+00			2.9	123.1		S. edge ser. rd. N. old hos.
7+00	5.32	128.86	2.41		123.54	T.P.
8+00			4.7	124.2		℄ existing mac. rd. off center entrance
9+00			3.4	125.5		old hos.
10+00			4.6	124.3		℄ S. edge ser. rd. N. old hos.
10+00	0.88	125.46	4.28		124.58	T.P.
10+70			3.8	121.7		Top of slope
11+00			6.4	119.1		

Checked: Bedell

Leveler: H.L. Chippeaux   Dumpy Level #12328
Rodman: C.F. Browning

(12)

PROFILE LEVELS FOR ROAD   FROM ⊙T.P. TO ℄19+00

Sta.	+B.S.	H.I.	−F.S.	Elev.	Elev. T.P.	Remarks: Nov. 16, 1939 (2½ hours) Fair, windy
T.P.	0.26	113.15	12.57		112.89	
11+70			6.3	106.9		Bottom of slope
12+00			9.3	103.9		
12+00	0.73	104.93	8.95		104.20	T.P.
13+00			4.7	100.2		S. edge of old r.r. rt. of way
13+24			9.5	95.4		Bottom of stream bed 15' wide 5' deep
14+00			6.7	98.2		
14+60			6.9	98.0		
14+60	1.70	100.18	6.45		98.48	T.P. Change of direction
15+00			5.7	94.5		
T.P.	8.27	98.57	9.88		90.30	
15+59			12.0	86.6		N. bank of stream 8' deep
15+84			10.0	88.6		S. bank of stream 8' deep
16+00			8.8	89.8		Bottom of slope
T.P.	11.80	110.06	0.31		98.26	
T.P.	12.54	121.98	0.62		109.44	
17+00			7.9	114.1		
T.P.	10.71	132.56	0.13		121.85	
17+42			9.1	123.5		Top of slope
18+00			7.0	125.6		
19+00			1.00		131.56	N. edge of old ser. rd.
	77.74		69.68		123.50	
			77.74		8.06	
			8.06			

Checked: Bedell

Figure 11–19.—Profile notes.

The first step is to decide from an examination of the range of the elevations where to start the drawing on the paper so that it will be centrally located and will fall within the limits of the sheet. First, the profile is drawn in pencil, using the rulings of the profile paper as a scale, and afterwards it is inked in. All surface elevations should be checked by reading from the profile station and elevation of each point as it is plotted and comparing them with the original data. Profile notes are shown in figure 11–19, and the completed profile drawn from these notes, in figure 11–20.

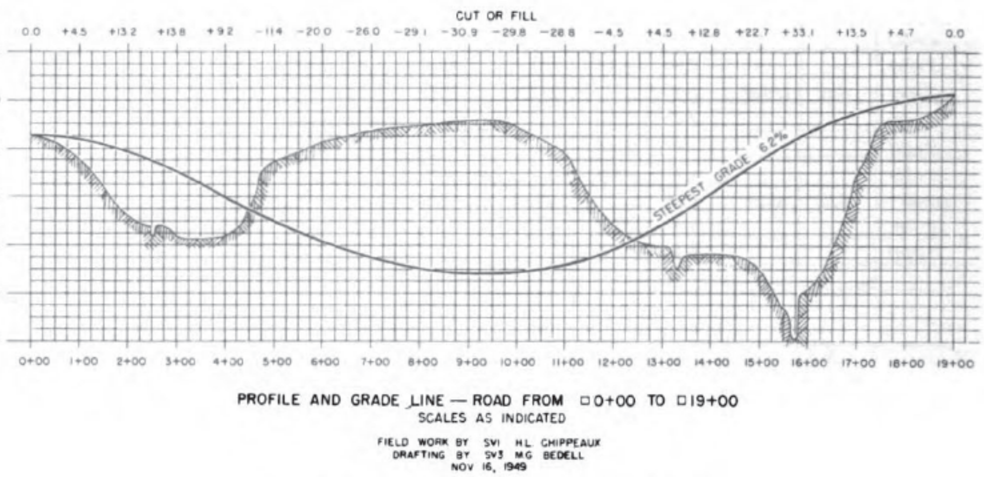
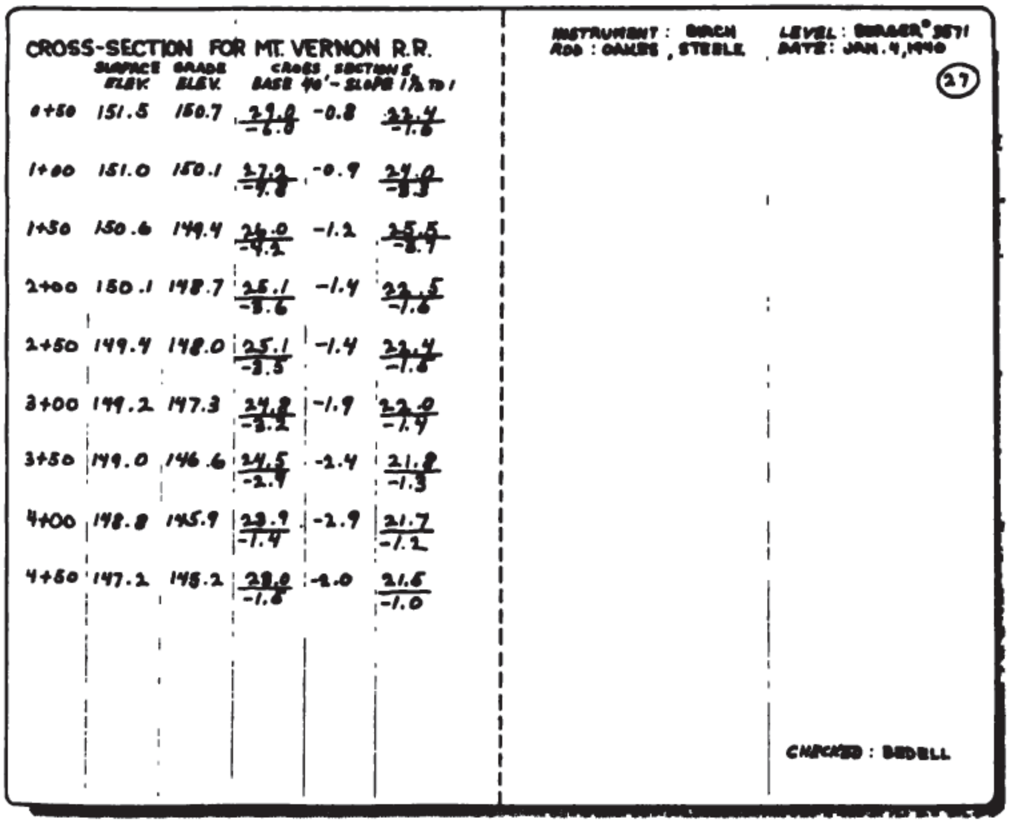


Figure 11–20.—Profile and grade line.

As the concluding step in making the profile, the grade line is drawn through the ruling points, allowing for smooth vertical curves, taking into account the controlling conditions, such as a maximum allowable gradient of railroad, ditch, drain, etc. After laying the grade line on the profile, the cut or fill is indicated as differences in elevation between the ground and grade profiles. These are shown for every 50 feet (or less in rock) to 100 feet of profile, and in figure 11–20, they are placed at the top of the drawing, with plus (+) indicating a fill and minus (−) indicating a cut.

Cross sections are used to determine the amount of earth to be moved to bring the ground to the proper grade. These

cross sections are plotted after the field party obtains the necessary data and returns it to the drafting room. Notes similar to the first three columns in figure 11–21 are first made from the profile. Column 5 in the figure indicates the cut (or fill) on the centerline of the roadway. The field party fills in the other two columns. Column 4 indicates a number of feet to the left of the centerline, with the cut or fill entered under the number of feet, and column 6 indicates a number of feet to the right of the centerline, with cut (or fill) entered underneath.



CROSS-SECTION FOR MT. VERNON R.R.

INSTRUMENT: BIRCH LEVEL: BERGER 3571
ROD: OAKES, STEELE DATE: JAN. 4, 1940

(27)

	SURFACE ELEV.	GRADE ELEV.	CROSS SECTIONS BASE 40'–SLOPE 1½ TO 1		
0+50	151.5	150.7	$\frac{29.0}{-6.0}$	-0.8	$\frac{22.4}{-1.6}$
1+00	151.0	150.1	$\frac{27.2}{-4.8}$	-0.9	$\frac{24.0}{-3.3}$
1+50	150.6	149.4	$\frac{26.0}{-4.2}$	-1.2	$\frac{25.5}{-3.7}$
2+00	150.1	148.7	$\frac{25.1}{-3.6}$	-1.4	$\frac{22.5}{-1.6}$
2+50	149.4	148.0	$\frac{25.1}{-3.5}$	-1.4	$\frac{22.4}{-1.6}$
3+00	149.2	147.3	$\frac{24.8}{-3.2}$	-1.9	$\frac{22.0}{-1.4}$
3+50	149.0	146.6	$\frac{24.5}{-2.4}$	-2.4	$\frac{21.8}{-1.3}$
4+00	148.8	145.9	$\frac{23.9}{-1.4}$	-2.9	$\frac{21.7}{-1.2}$
4+50	147.2	145.2	$\frac{23.0}{-1.8}$	-2.0	$\frac{21.6}{-1.0}$

CHECKED: BEDELL

Figure 11–21.—Cross section notes.

From the notes shown in figure 11–21, cross sections are drawn as shown in figure 11–22. Cross sections are usually drawn in pencil on heavy cross-section paper subdivided equally in both horizontal and vertical directions, usually 10 subdivisions to the inch. Each cross section is identified by a number which expresses the distance from the zero station of the profile line as 0+50, 1+00, 1+50, etc.

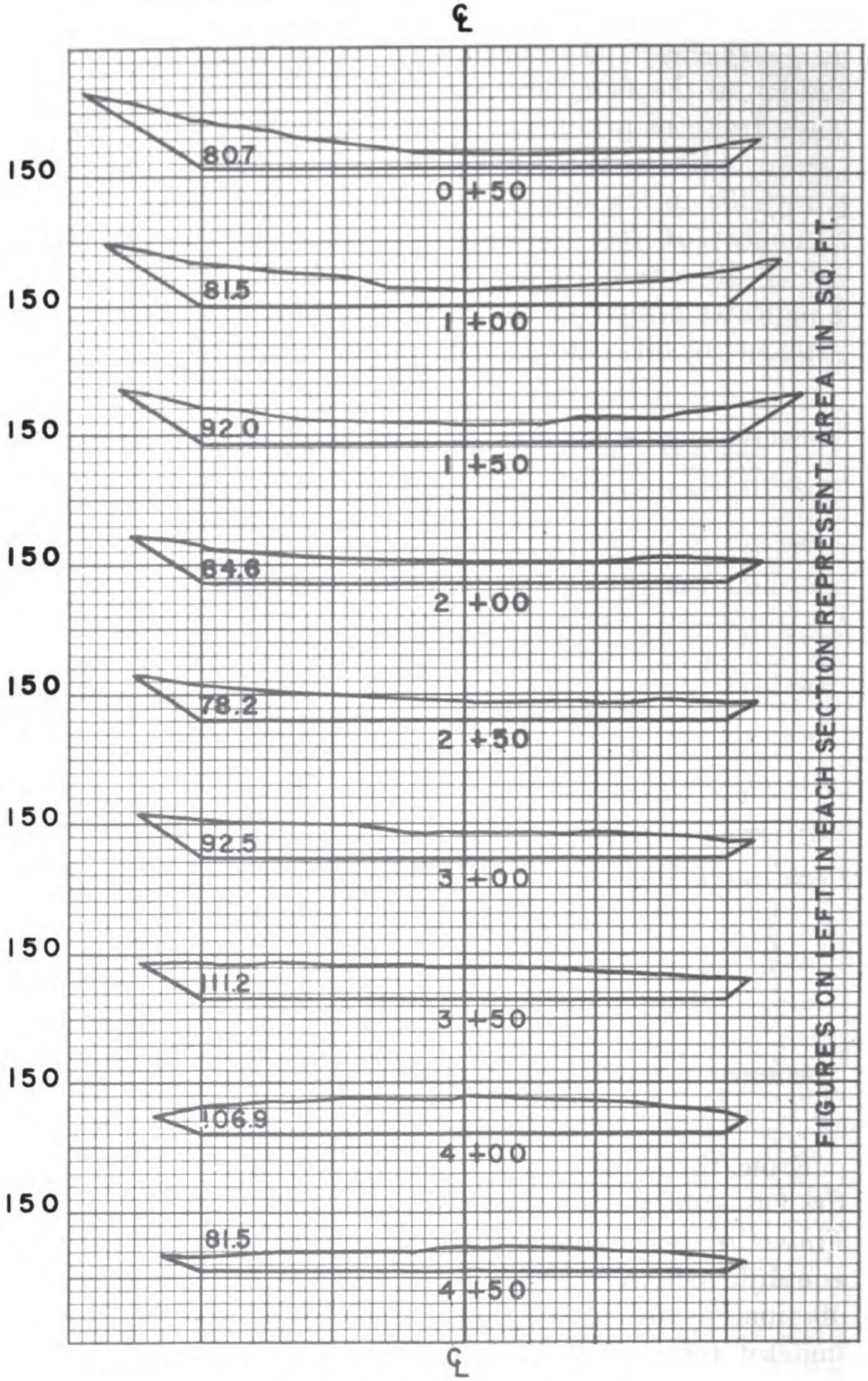


Figure 11–22.—Cross section for road.

To obtain the areas of cut and fill for computing earth quantities, the undisturbed ground line and the finished cut or fill line for each section must be plotted. First, a convenient base elevation, which should be large enough to accommodate all the cross sections for 1 project, is assumed and marked on one of the heavy horizontal lines of the cross-section paper. Then the usual procedure is to plot the ground cross section before the excavation or fill is started, and as the excavation progresses, plot the cross sections of cut or fill and take off the quantities between ground line and cut or fill line with a planimeter.

To calculate the quantities of earth to be moved, the area of each cross section must first be obtained. The areas are tabulated as shown in figure 11–23, keeping cut and fill separate. The volume is then computed from the areas of the cross sections. The simplest method of doing this is to average the areas of each two adjacent sections and multiply by the distance between them. Thus,

$$V=\left(\frac{A_1+A_2}{2}\right)\times l \text{ (end area formula)},$$

in which A_1 and A_2 are the areas of the two sections and l is the distance between them. This method is used very extensively, although it does not give sufficiently accurate results for certain classes of work.

A more nearly correct value may be determined by using the prismoidal formula:

$$V=\tfrac{1}{6}(A_1+4A^m+A_2)\times l,$$

in which l is the distance between the two sections A_1 and A_2, and A^m is the area of the middle section; that is, the area of a section halfway between the two end sections. For this purpose, three adjacent sections are taken, A_1 and A_2 being the first and third respectively, and A^m being the second. Thus, the area of every alternate section becomes the area of a middle section. The total volume of earth to be moved is obtained by adding separately all cuts and all fills, converting each total into cubic yards.

CROSS-SECTION FOR MT. VERNON R.R.

Instrument: Birch
Rod: Oakes, Steele

Level: Berger #3571
Date: Jan 4, 1940

(27)

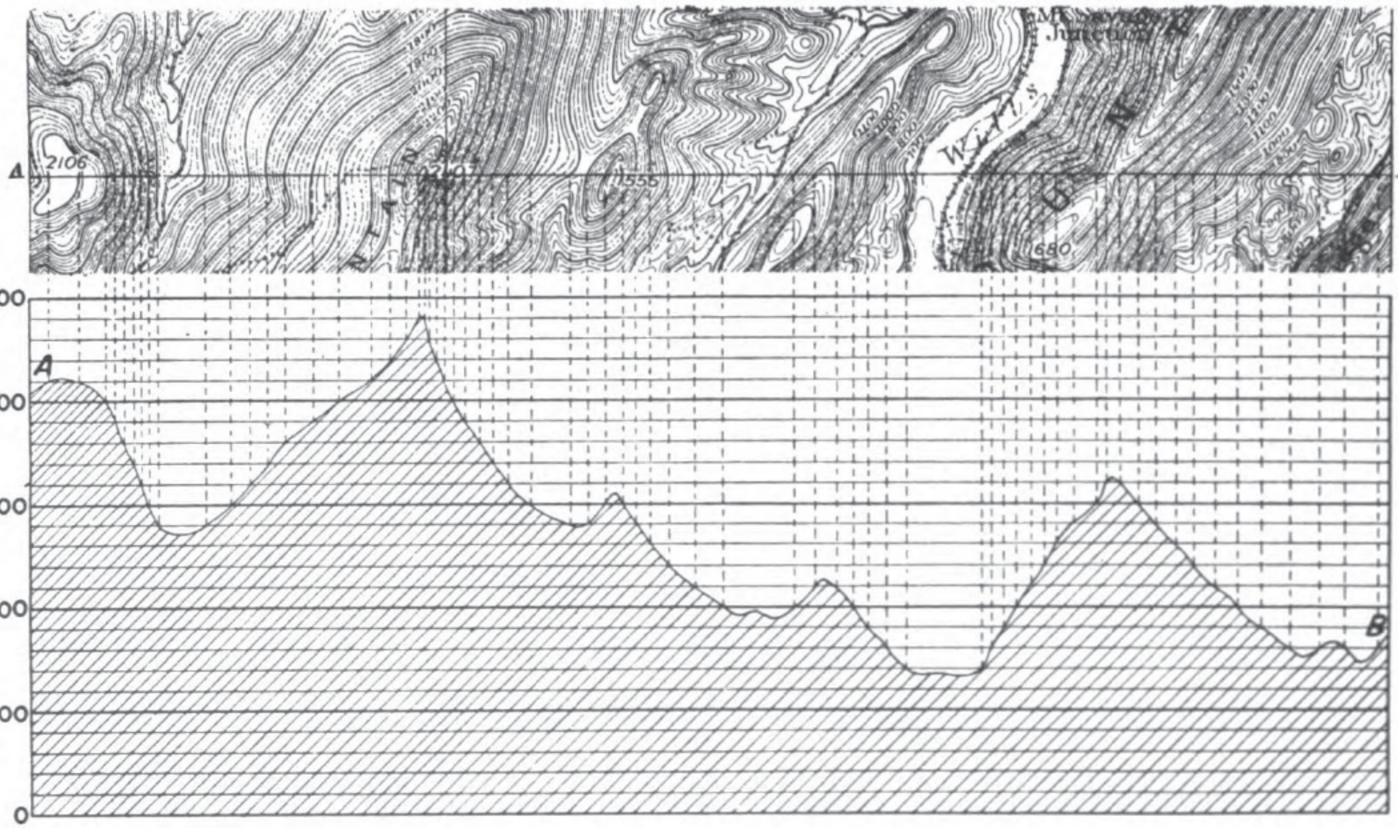
	Surface Elev.	Grade Elev.	Cross-Sections Base 40. Slope 1½ to 1			Area of Section in Sq. Ft.	CUT	FILL	Remarks
0+50	151.5	150.7	29.0 / −6.0	−0.8	22.4 / −1.6	80.7	4035.0	——	No excavation at 0+00. Figures for Cut and fill are Cu. Ft.
1+00	151.0	150.1	27.2 / −4.8	−0.9	24.0 / −3.3	81.5	4075.0	——	
1+50	150.6	149.4	26.0 / −4.2	−1.2	25.5 / −3.7	92.0	4600.0	——	
2+00	150.1	148.7	25.1 / −3.6	−1.4	22.5 / −1.6	84.6	4230.0	——	
2+50	149.4	148.0	25.1 / −3.5	−1.4	22.4 / −1.5	78.2	3910.0	——	
3+00	149.2	147.3	24.8 / −3.2	−1.9	22.0 / −1.4	92.5	4625.0	——	
3+50	149.0	146.6	24.5 / −2.9	−2.4	21.8 / −1.3	111.2	5560.0	——	
4+00	148.8	145.9	23.9 / −1.4	−2.9	21.7 / −1.2	106.0	5030.0	——	
4+50	147.2	145.2	23.0 / −1.5	−2.0	21.5 / −1.0	81.5	4075.0	——	
							40140.0		

Checked: Bedell

Figure 11–23.—Earthwork computation from cross-section notes.

In connection with drainage and irrigation work, the grading of earthwork, location and construction of buildings, etc., it is often desirable to obtain the shape of the surface of a piece of land. This may be done by dividing the area into a system of squares, and then determining the elevations of the corners and other points where changes of slope occur. The length of the sides of the squares are from 25 feet to 100 feet. The data obtained by this method may be used in the construction of a contoured map, or to plot cross sections of any portion of the area.

Cross sections may also be drawn from large-scale topographic maps. Figure 11–24 is a portion of a topographic map showing mountainous terrain and a section taken from this map along the line AB. In the section, the 100-foot map contour intervals along the line AB are used to obtain the profile which is represented by the irregular line on the cross-section paper.



AREA OF MARKED RELIEF   PART OF FROSTBURG (MD.-W. VA.-PA.) SHEET, WITH SECTION ON LINE A-B

Scale 1:62500

1 ½ 0 1 2 miles

Contour interval 20 feet.

Datum is mean sea level.

Figure 11–24.—Cross section from topographic map.

First, the line AB was drawn on the map. Then on a piece of profile paper, the zero elevation line was drawn. The highest elevation was determined by inspecting the map along the line AB. At the left end of the zero elevation line, 100-foot intervals are counted up to 2,500 feet, the nearest 100 feet above the highest elevation of 2,407 feet. Then each intersection of a 100-foot contour line with the line AB is plotted on the cross-section paper. Finally, the profile line is drawn through the plotted points. With the use of proportional dividers, the cross section may be easily drawn to a larger scale than the scale of the map.

COMPUTATIONS AND PLOTTING

Field records and computations include all field notes normally recorded in special field notebooks or on special forms and all computations made by field parties or at field headquarters. Computations that pertain to surveying and topographic work are to a great extent calculations based on observations in the field and constitute the final phase of obtaining the necessary controlling data on which maps are based. While most computations are made on special forms, some minor computations, of which only the final values are recorded, are often made to complete certain field notes.

Independent office computations and adjustments include certain check computations referred to in the preceding paragraph and computations incidental to office work, such as are necessary for laying out projections, grids, plotting of incomplete control data, etc.

The draftsman will be called upon to convert geographic data, such as geographic coordinates, azimuths, etc., pertaining to ground control stations, into grid coordinates and grid azimuths. Geographic data are usually furnished by other survey and mapping agencies and must be converted to conform with the plane survey grid system.

For small areas, within a radius of 20 or 25 miles, the conversion of geographic to plane coordinates may be simply and effectively made as shown in figure 11–25 and plane to

geographic coordinates as shown in figure 11–26, which are taken from the Bureau of Yards and Docks publication NavDocks TP–Te–1, *Surveys, Drawing, and Specifications.* For latitudes embracing the United States, tables for these conversions are given in the U. S. Coast and Geodetic Survey Special Publication 71, and their counterpart in natural functions tables in Special Publication 241. In extending

Example		
N 40° 36′ 15″. 867	New Station	W 74° 03′ 23″. 433
40° 36′ 07″. 650	Origin	74° 06′ 58″. 013
(1) $\Delta\varphi''$ + 8″. 217		(2) $\Delta\lambda''$ − 3′ 34″. 580
(3) log $\Delta\lambda''$		2.3315898
(4) log H		1.8872404
(5) log X		4.2188306
(6) X	−	16,551.550
(7) log X^2		8.43766
(8) log L		2.31073−10
(9) log LX^2		0.74841
(10) LX^2		+5.603
(11) log $\Delta\varphi''$		0.9147133
(12) log K		2.0051783
(13) log $\Delta\varphi''$. K		2.9198916
(14) $\Delta\varphi''$. K		+ 831.556
(15) Y = 837.159		

Explanation	
(1)	Latitude difference in seconds
(2)	Longitude difference in seconds
(3)	Log. of (2) (214.580 seconds)
(4)	From tables, for latitude of New Station, USC & GS Spec. Pub. 71
(5)	(3) plus (4)
(6)	(5) expressed in feet
(7)	(6) times 2
(8)	From tables, for latitude of Origin, USC & GS Spec. Pub. 71
(9)	(7) plus (8)
(10)	(9) expressed in feet
(11)	Log. of (1)
(12)	Mean of latitude of Origin and New Station
(13)	Log $\Delta\varphi''$. K
(14)	$\Delta\varphi''$. K expressed in feet
(15)	(14) plus (10). Watch the algebraic signs. LX^2 is always plus. (1) is plus if $\Delta\varphi''$ is North. (2) is plus if $\Delta\lambda''$ is West

This table gives the method of converting geographic coordinates to plane rectangular coordinates for values of H, K, and L in Latitudes 24 deg. to 49 deg.

For other latitudes, compute the X and Y of each new station from origins, as in the table. Compute plane coordinates of each new station from origins. Then compute bearing and distance between any two new stations. To compute tables of values for H, K, and L for latitudes less than 24 deg and greater than 49 deg, see USC&GS Spec. Pub. No. 8.

Figure 11–25.—Geographic to plane coordinate.

Example		
Y + 837.159 ft	New Station	X − 16,551.550 ft
0.0	Origin	0.0
① Y + 837.159 ft		② W − 16,551.550 ft
③ log X		− 4.2188386
④ log H		+ 1.8872494
⑤ log Δλ″		− 2.3315892
⑥ Δλ″		− 214.580
⑦		= − 0° 03′ 34″.580
⑧ long Origin W		74° 06′ 58″.013
⑨ long New Station W		74° 03′ 23″.433
⑩ log X^2		− 8.43768
⑪ log L		+ 2.31074−10
⑫ log LX^2		− 0.74841
⑬ LX^2		− 5.603
⑭ $Y - LX^2 =$		+ 831.566 ft
⑮ $\Delta\varphi'' = \frac{831.566}{101.205} =$		+ 8″.217
⑯ lat Origin N		40° 36′ 07″.650
⑰ Δφ″		+ 8.217
⑱ lat New Station N		40° 36′ 15″.867

Explanation

① and ② Given
③ Log. of ②
④ H for latitude of New Station, USC & GS Spec. Pub. 71
⑤ Log. ③ divided by log. H = log. Δλ″
⑥ Difference between New Station and Origin, seconds
⑦ To east of Origin, therefore, is minus
⑧ Origin, longitude is West of Greenwich
⑨ New Station
⑩ ③ times 2
⑪ L for latitude of Origin, USC & GS Spec. Pub. 71
⑫ Log. X^2 times log. L
⑬ is minus, see Plate I-d
⑭ ① minus ⑬
⑮ ⑭ divided by meridional arc distance for 1 second at latitude of New Station. This distance can be interpolated very closely from table below
⑯ Origin ⑰ Origin—New Station, in seconds
⑱ Latitude of New Station

Meridional arc distances for 1 second longitude at any latitude			
lat 0° 100.764 ft	lat 25° 100.948 ft	lat 50° 101.368 ft	lat 75° 101.726 ft
lat 5° 100.771 ft	lat 30° 101.020 ft	lat 55° 101.456 ft	lat 80° 101.765 ft
lat 10° 100.797 ft	lat 35° 101.102 ft	lat 60° 101.535 ft	lat 85° 101.788 ft
lat 15° 100.833 ft	lat 40° 101.187 ft	lat 65° 101.611 ft	lat 90° 101.798 ft
lat 20° 100.866 ft	lat 45° 101.279 ft	lat 70° 101.676 ft	

Figure 11–26.—Plane to geographic coordinate.

these tables for other latitudes, use the formula in Special Publication 71.

The need for permanently referencing local engineering surveys by converting their plane coordinates to geographic positions (latitude and longitude) led, in 1933, to the establishment of the State Coordinate System for the Lambert and transverse Mercator projections, which are discussed in chapter 13. The projection used depends on the shape of the particular State or group of States involved, and the projection chosen is the one that gives the least distortion. The Lambert is better adapted to States having shorter north-south dimensions; the transverse Mercator is better for States having shorter east-west dimensions.

A State index map showing the extent of geodetic surveys and whether they have been executed in the vicinity of a Navy project is available from the Director, U. S. Coast and Geodetic Survey, Washington 25, D. C. If such a survey exists, and if quadrangle sheets have been executed for the area, a list of geographic positions and BM's and the plane-coordinate projection tables for the area should be procured.

The State Coordinate System references surveys to the origin for the State in which the survey occurs. The World-wide Polyconic System references the survey to 1 of the 9 zones comprising each of the 5 bands circling the earth in each hemisphere. The zones are 9 degrees wide, each zone overlapping 1 degree.

Rectangular Coordinates

Rectangular coordinates are distances north or south and east or west from a fixed point, called the origin, to any other point. These distances are measured along lines parallel with 2 lines intersecting at right angles at the origin, the 2 lines running south-north and west-east through the origin. (See chapter 4.) Thus, when the positions of any number of points are given by their distances from a common origin, the distance and direction with respect to each other can be obtained by plotting or computing. The location of a point is always expressed by two values: the difference in

latitude and the difference in longitude as measured from the origin, usually expressed in feet, yards, or meters. The difference in latitude is called *latitude*, and the difference in longitude, *departure.*

In figure 11–27, it is assumed that the rectangular coordinates, in yards, of five different stations, A, B, C, D, and E, on a closed traverse, are:

Station	*Latitude*	*Departure*
A	100, 000	100, 000
B	103, 000	102, 000
C	104, 000	105, 000
D	102, 000	106, 000
E	99, 000	104, 000

A, the origin, is assigned coordinates of 100,000 for both its latitude and departure to avoid the use of plus and minus signs. As shown in figure 11–27, in which the lines are 1,000 yards apart, A lies at the intersection of the 100,000 west-east and the 100,000 south-north line. Likewise, B, C, D, and E fall on lines parallel to A's 100,000 line.

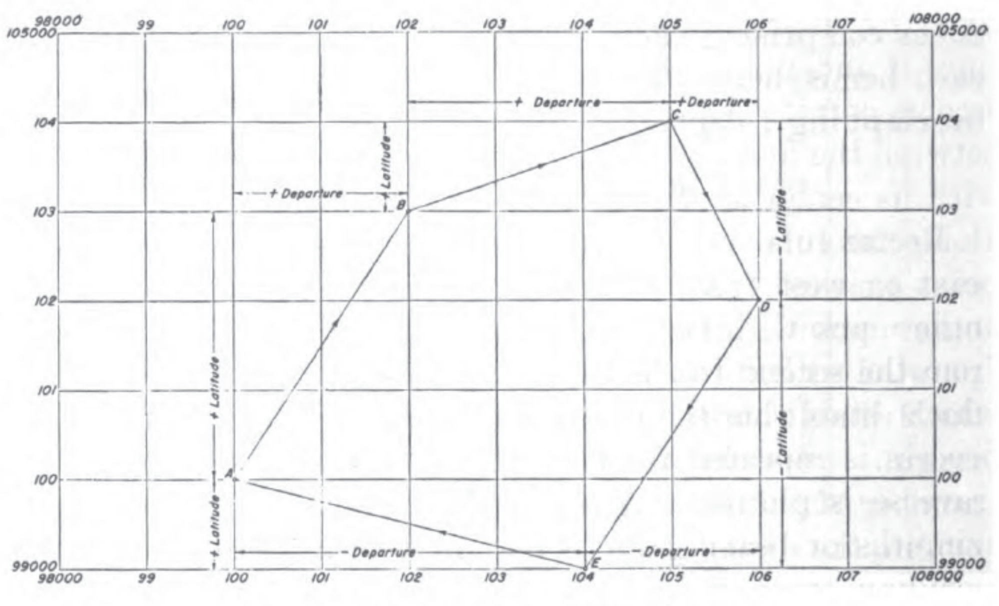


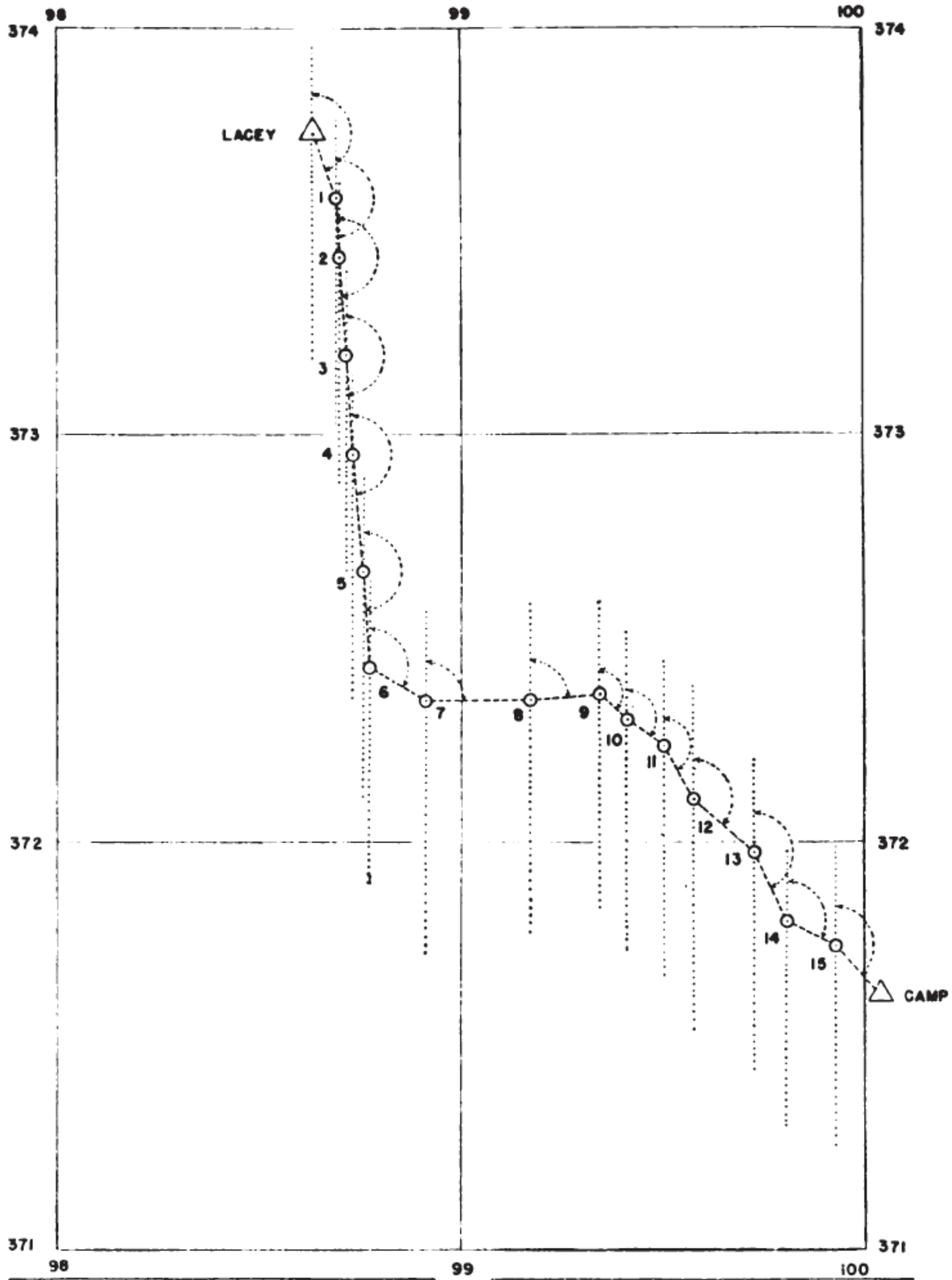
Figure 11–27.—Rectangular coordinates.

Plotting Methods

The plotting methods in this section are used for maps of smaller areas where the earth's surface can be considered plane. They are applicable to all types of surveys and are used mostly at the beginning of making a map. In general, these methods are those used in plotting horizontal control. Such control may be plotted by use of the protractor and scale, by the tangent method, chord method, or rectangular coordinate method. The two methods in general use are the protractor and scale method and the rectangular coordinate method. Control stations are indicated by appropriate symbols.

Ordinarily the method of plotting by protractor and scale is used only when the control system, usually a traverse, is not extensive or important. Since a protractor is used to plot the angular values, either from direct angular measurement or from azimuths and bearings, and since the precision with which angles can be laid off varies directly with the diameter of the protractor, it is of advantage to use the largest protractor available.

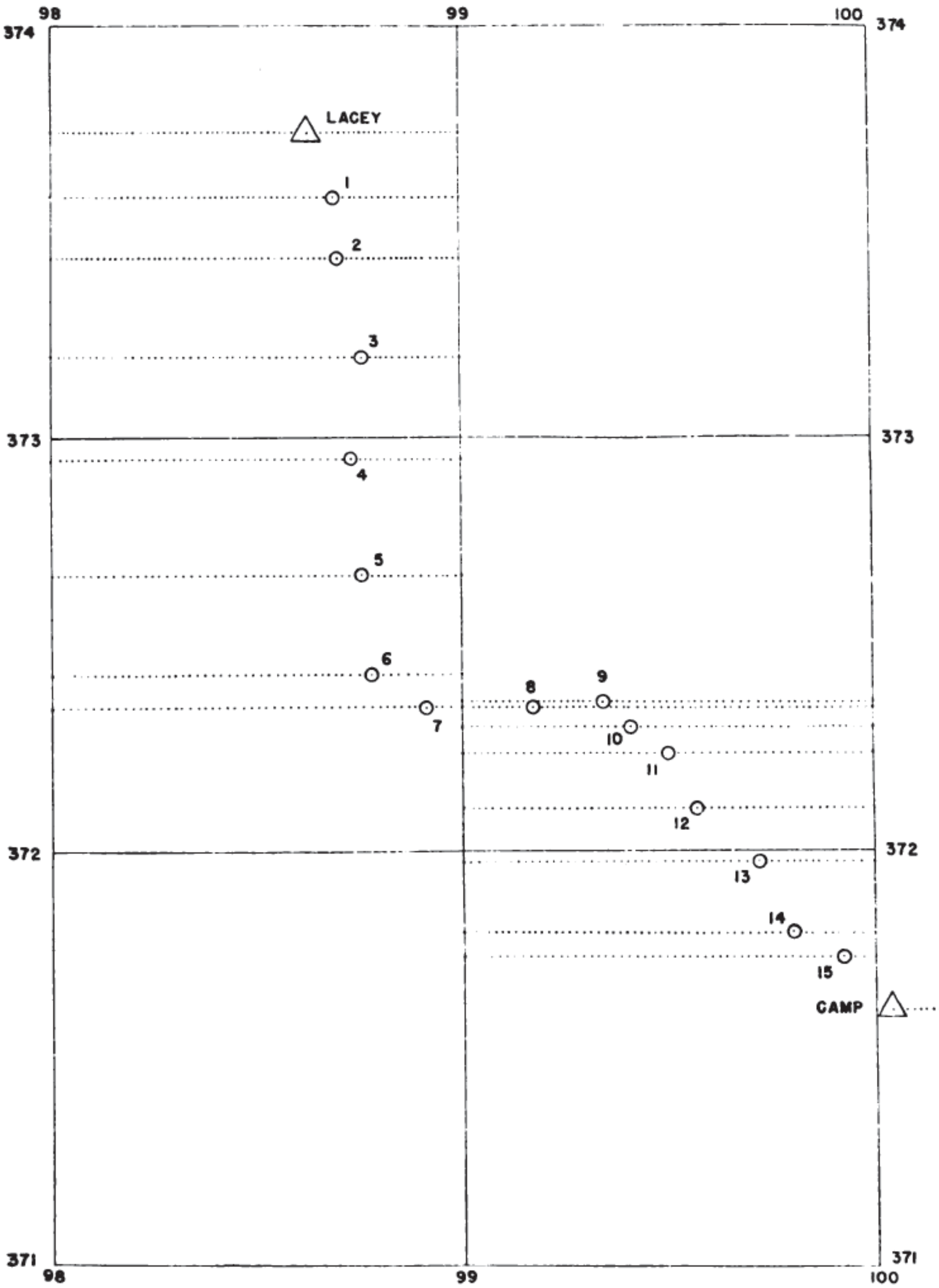
In plotting the stations of a traverse by the actual angular values between them, the position of the first point is fixed by estimation, if not previously known, and a fine line of indefinite length is drawn in the direction of the second point. Along this line is laid off the given distance between the first and second point. The protractor is placed with its center at the second point and its 0° to center edge along the line just drawn, and the angle to the succeeding point marked. A fine line is then drawn connecting the angle mark with the second station, and the given distance from the second to the third station laid off along this line, which establishes the position of the succeeding point. The process is repeated for each traverse point until the entire traverse is plotted. When stations are to be plotted from azimuths or bearings, it is best to determine and draw the meridian—true or grid north—and plot all angles in logical succession by their bearings with respect to the meridian. If



STATION	DISTANCE	AZIMUTH
△LACEY – ⊙ 1	167.9 YDS	160° 28′ 00″
⊙ 1 – ⊙ 2	150.0	177 25 00″
⊙ 2 – ⊙ 3	238.0	175 53 30
⊙ 3 – ⊙ 4	246.6	175 58 30
⊙ 4 – ⊙ 5	285.3	175 14 00
⊙ 5 – ⊙ 6	239.3	175 51 00
⊙ 6 – ⊙ 7	161.2	120 46 00
⊙ 7 – ⊙ 8	258.6	89 03 00

STATION	DISTANCE	AZIMUTH
⊙ 8 – ⊙ 9	172.7 YDS.	85° 58′ 00″
⊙ 9 – ⊙ 10	90.7	130 40 30
⊙ 10 – ⊙ 11	110.5	126 24 00
⊙ 11 – ⊙ 12	148.4	151 46 30
⊙ 12 – ⊙ 13	200.9	130 20 00
⊙ 13 – ⊙ 14	188.2	154 17 00
⊙ 14 – ⊙ 15	135.3	116 06 30
⊙ 15 – △ CAMP	169.2	138 43 30

Figure 11–28.—Plotting traverse by protractor and scale.



STATION	NORTHINGS	EASTINGS	STATION	NORTHINGS	EASTINGS
△ LACEY	373741.8	98636.2	⊙ 9	372362.3	99343.2
⊙ 1	373583.7	98692.2	⊙ 10	372303.3	99411.9
⊙ 2	373434.0	98699.0	⊙ 11	3722378	99500.7
⊙ 3	373196.7	98716.1	⊙ 12	372107.1	99570.8
⊙ 4	372950.9	98733.4	⊙ 13	371977.1	99723.8
⊙ 5	372666.8	98757.0	⊙ 14	371807.6	99805.4
⊙ 6	372428.3	98774.2	⊙ 15	371748.2	99926.8
⊙ 7	372345 9	98912.6	△ CAMP	371621.1	100038.8
⊙ 8	372350.2	99171.0			

Figure 11–29.—Plotting traverse by rectangular coordinates.

azimuths only are given, they must be converted to their corresponding bearing for plotting. (See fig. 11–28.) The weakness of plotting stations successively from previous stations is that an error, once made, will be carried forward in locating other stations.

Plotting by rectangular grid coordinates is the only practical and satisfactory method for plotting the positions of control stations in any system of horizontal control. The rectangular coordinates (or grid) having been constructed, and the lines numbered so that all the points to be shown will fall within the numbered area, each station is plotted as follows:

1. After comparing the rectangular coordinates of the station (found in the coordinates column under northings and eastings respectively, on the traverse sheet, fig. 11–29) with the numbered lines, select the proper square within which the station to be plotted will fall.
2. With a pair of dividers or scale lay off along both south-north lines bordering this square the difference in northings between the stations and the grid line below it.
3. Using a single triangle, draw a fine line connecting the two prick marks made with the dividers. This line should be perfectly parallel to the west-east lines.
4. Now lay off along this newly drawn line the difference in eastings between the station and the 1,000-yard grid line to the left of it.
5. Mark and label the plotted station.
6. Repeat the operations until all stations are plotted.
7. For a check always compare the scale distance between the last two plotted stations with the known recorded or computed distance. (See fig. 11–29).

TIDE TABLES

The vertical rise and fall of the ocean level caused by the gravitational force between the earth and the moon (and, to a lesser extent, between the earth and the sun) is called TIDE. The highest level reached by an ascending tide is called

HIGH WATER, the minimum level of a descending tide, LOW WATER. At high and low water there is a brief period during which there is no change in the water level, and this period is called STAND.

The total rise or fall from low water to high, or vice versa, is called the RANGE of the tide. The actual height of the water level at high and low water varies with phases of the moon, variations of wind force and direction, and from other causes. The average height of high water measured over a period is called MEAN HIGH WATER. The average height of low water, measured in the same way, is MEAN LOW WATER. The plane midway between mean high and mean low water is MEAN SEA LEVEL. The datum for Navy installations on the Atlantic and Gulf coasts is mean low water, and for the

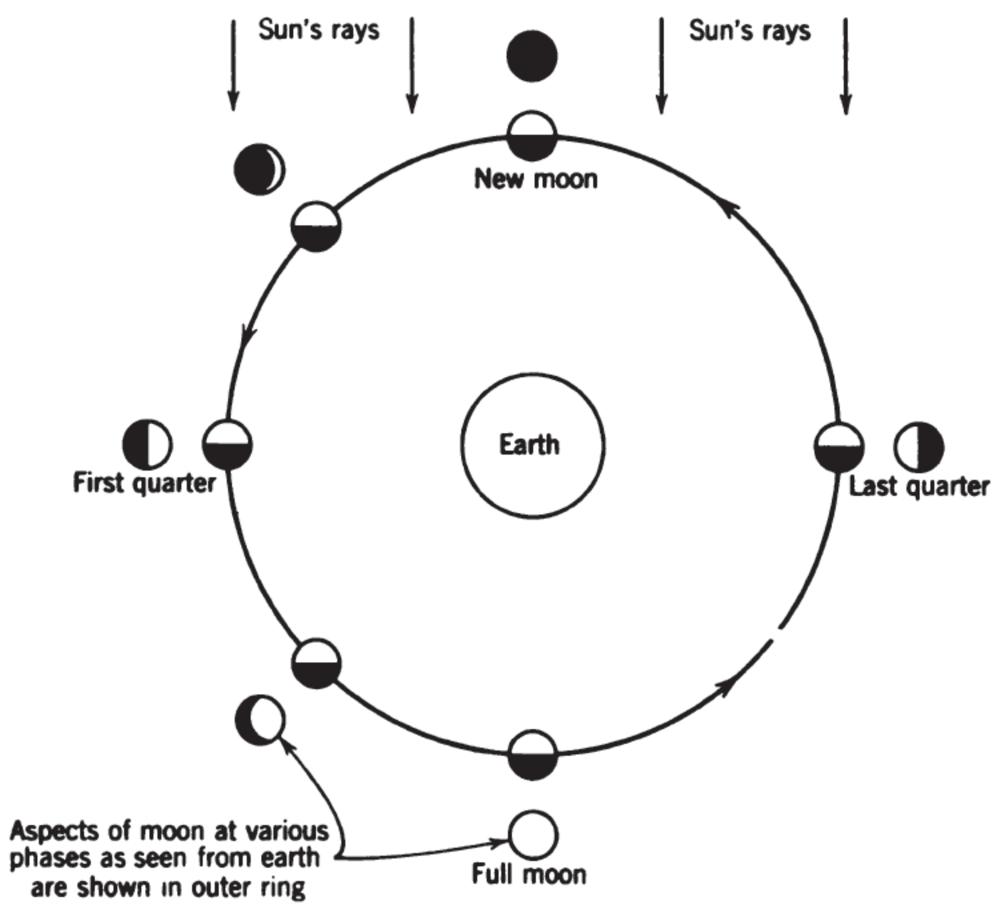


Figure 11–30.—Phases of the moon.

Pacific coast, mean lower low water. Continental leveling is based on mean sea level.

SPRING TIDES occur near the time of full moon and new moon, at which time the sun and moon act together to produce tides higher and lower than average. When the moon is in its first or last quarter, it and the sun are opposed to each other, and NEAP TIDES of less than average range occur. (See fig. 11–30.)

There are usually 2 high tides and 2 low tides each lunar day. Because of the relative positions of the sun and moon with respect to the earth and each other, there is an infinite variety of tidal situations, so that the height of the water level varies from tide to tide, and from day to day. The lower of the 2 low tides in any 1 day is called LOWER LOW WATER.

Reading the Tide Tables

The ability to read tide tables is valuable in connection with hydrographic surveys and chart construction, as well as in navigation. The following tables are published annually in advance, by the U. S. Coast and Geodetic Survey:

Tide Tables, Central and Western Pacific Ocean and Indian Ocean.

Tide Tables, East Coast North and South America (including Greenland).

Tide Tables, Europe and West Coast of Africa (including Mediterranean Sea).

Tide Tables, West Coast North and South America (including Hawaiian Islands).

Table 1 in each volume gives the time and height of tide at each high and low water for a number of principal ports, called REFERENCE STATIONS. Because the lunar or tidal day is a little more than 24 hours in length, the time between successive high or low tides is a little more than 12 hours. Therefore, when a high or low tide occurs just before midnight, the next high or low tide will occur at

about noon on the following day, and the next just after the ensuing midnight. Under these conditions, 3 consecutive high or low tides may occur on 3 different dates, the total interval involved being no longer than the period of a lunar day. When this occurs, only 1 tide is shown in table 1 for the middle day of the 3 and dots are run in, in place of the second tide.

Height of tide has no reference to actual depth of water, nor does the charted depth shown by a sounding on a chart indicate the lowest depth to be found at all times at that particular point. MEAN LOW WATER, for example, is only an average of the various depths actually sounded there at low water during a survey. The charted depth is the vertical distance from the reference plane, on which soundings are based, to the ocean bottom. The charted depth with this same reference plane is used as the basis for the figures for high and low water which are given in the tide tables. As you see, the actual depth of water can be less than the charted depth, or below the reference plane. This is indicated by a minus sign placed before the height of tide shown in the tide tables. The depth of water, then, is equal to the algebraic sum of the charted depth and the height of tides as given in the tables.

Table 2 in each volume contains a list of secondary or subordinate stations. The latitude and longitude of each of these is given. Under the heading DIFFERENCES, the difference in time and height of tides between the secondary stations and the reference station are listed. The time meridian and the reference station used are also given.

For example, suppose you wish to find the height of tide at George Washington Bridge in New York at 1500 on Friday 3 September 1954. First turn to table 2 in *Tide Table, East Coast North and South America* (including Greenland) and find George Washington Bridge in the left-hand column. The page on which it is found in the volume for 1954 is shown in figure 11–31. Note that NEW YORK, printed in bold type in the DIFFERENCES column, is the reference sta-

tion for George Washington Bridge. The time meridian is 75° W. This means that the times listed are zone times plus 5.

Now look at the headings under differences. The time given for George Washington Bridge is plus 45 minutes, which means simply that high and low tides occur 45 minutes later at the bridge than they do at New York, the reference station. In other words, you must add 45 minutes to any time of tide given in table 1 under New York. If the sign were a minus, it would mean that the tide occurred earlier and you would subtract the time given from the time at the reference station.

Under height, high water is the figure −0.5. This means that the height of high water at the George Washington Bridge is 0.5 foot less than the height of high water at New York, the reference station. Height of low water is listed as 0.0, indicating that no adjustment need be made in the height of low water under the reference station. A plus (+) sign always indicates that the difference should be added to the height at the reference station and a minus (−) sign that it should be subtracted.

Now you have the differences you need to apply to the data on the reference station in table 1. Page 62 from that table is shown in figure 11–32. Running down the column for September, find the date 3 F (Friday) and note that at New York a high water will occur at 1157 and a low water at 1813 on that date. Applying the difference (plus 45 minutes) from table 2 for George Washington Bridge, you find that high tide occurs at 1242 and low tide at 1858 at the bridge.

Since 1500 comes after the time of high water, you know that the tide is falling (ebbing) at that time. By subtracting 1242 from 1858, you find that it takes 6 hours and 16 minutes for the tide to go all the way out at the bridge. By subtracting 1242 from 1500, you learn that the time you are concerned with is 2 hours and 18 minutes past high water.

No.	PLACE	POSITION Lat.	Long.	DIFFERENCES Time	Height High water	Low water	RANGES Mean	Spring
		° ′	° ′	h. m.	feet	feet	feet	feet
	NEW YORK AND NEW JERSEY—Con.							
	Hudson River‡	N.	W.	*Time meridian, 75° W.* on **NEW YORK,** p. 62				
838	Jersey City, Pa. R. R. Ferry, N. J.	40 43	74 02	+0 05	0.0	0.0	4.4	5.3
839	New York, Desbrosses Street	40 43	74 01	+0 10	0.0	0.0	4.4	5.3
840	New York, Chelsea Docks	40 45	74 01	+0 15	−0.1	0.0	4.3	5.2
841	Hoboken, Castle Point, N. J.	40 45	74 01	+0 15	−0.1	0.0	4.3	5.2
842	Weehawken, Days Point, N. J.	0 46	74 01	+0 25	−0.2	0.0	4.2	5.0
843	New York, Union Stock Yards	40 47	74 00	+0 25	−0.2	0.0	4.2	5.0
845	George Washington Bridge	40 51	73 57	+0 45	−0.5	0.0	3.9	4.6
847	Yonkers	40 56	73 54	+1 10	−0.8	0.0	3.6	4.2
848	Dobbs Ferry	41 01	73 53	+1 35	−1.0	0.0	3.4	4.0
849	Tarrytown	41 05	73 52	+1 50	−1.2	0.0	3.2	3.7
850	Ossining	41 10	73 52	+2 05	−1.1	+0.2	3.1	3.6
851	Haverstraw	41 12	73 58	+2 10	−1.3	+0.2	2.9	3.4
852	Peekskill	41 17	73 56	+2 25*h* +3 00*l*	−1.2	+0.3	2.9	3.4
853	West Point	41 24	73 57	+3 25	−1.4	+0.3	2.7	3.1
854	Newburgh	41 30	74 00	+3 50	−1.4	+0.2	2.8	3.2
855	New Hamburg	41 35	73 57	+4 15	−1.4	+0.1	2.9	3.3
856	Poughkeepsie	41 42	73 57	+4 35	−1.2	+0.1	3.1	3.5
857	Hyde Park	41 47	73 57	+5 00	−1.2	0.0	3.2	3.6
858	Kingston Point	41 56	73 58	+5 25	−0.8	−0.1	3.7	4.2
859	Tivoli	42 04	73 56	+5 55	−0.7	−0.2	3.9	4.4
860	Catskill	42 13	73 51	+6 45	−0.6	−0.3	4.1	4.6
861	Hudson	42 15	73 48	+7 00	−0.8	−0.4	4.0	4.4
				on **ALBANY,** p. 66				
862	Coxsackie	42 21	73 48	−1 00*h* −1 40*l*	−0.5	+0.2	3.9	4.3
863	New Baltimore	42 27	73 47	−0 45	−0.1	+0.4	4.1	4.5
864	Castleton-on-Hudson	42 32	73 46	−0 25	−0.2	+0.1	4.3	4.7
865	**Albany**	42 39	73 45	Daily predictions			4.6	5.0
866	Troy	42 44	73 42	+0 10	+0.1	0.0	4.7	5.1
	The Kills and Newark Bay			on **NEW YORK,** p. 62				
	Kill Van Kull							
867	Constable Hook	40 39	74 05	−0 15	+0.1	0.0	4.5	5.4
868	New Brighton	40 39	74 05	−0 15	+0.1	0.0	4.5	5.4
869	Port Richmond	40 38	74 08	0 00	+0.1	0.0	4.5	5.4
870	Bergen Point	40 39	74 08	+0 05	+0.2	0.0	4.6	5.5
871	Shooters Island	40 39	74 10	+0 10	+0.2	0.0	4.6	5.5
872	Port Newark Terminal	40 42	74 09	+0 30	+0.6	0.0	5.0	6.0
873	Newark, Passaic River	40 44	74 10	+0 35*h* +1 10*l*	+0.7	0.0	5.1	6.1
874	Passaic, Gregory Ave. bridge, Passaic River	40 51	74 07	+0 50*h* +1 55*l*	+0.7	0.0	5.1	6.1
875	Little Ferry, Hackensack River	40 51	74 02	+1 30	+0.9	0.0	5.3	6.4
876	Hackensack, Hackensack River	40 53	74 02	+1 45	+0.9	0.0	5.3	6.4
	Arthur Kill			on **SANDY HOOK,** p. 70				
877	Elizabethport	40 39	74 11	+1 00	+0.2	0.0	4.8	5.8
878	Chelsea	40 36	74 12	+0 50	+0.4	0.0	5.0	6.0

‡Values for the Hudson River above George Washington Bridge are based upon averages for the six months May to October, when the fresh-water discharge is a minimum.
h=difference for high waters only.
l=difference for low waters only.

Figure 11–31.—A portion of the table of tidal differences and ranges, table 2, tide tables.

JULY

Day	High Time	High Ht.	Low Time	Low Ht.
	h. m.	ft.	h. m.	ft.
1	8 45	4.5	2 47	-0.6
Th	21 01	5.6	14 52	-0.2
2	9 38	4.5	3 32	-0.6
F	21 51	5.3	15 40	-0.1
3	10 31	4.5	4 17	-0.5
Sa	22 40	5.0	16 27	0.1
4	11 22	4.5	5 00	-0.3
Su	23 27	4.7	17 13	0.4
5	. ..	. .	5 42	0.0
M	12 09	4.4	18 03	0.7
6	0 13	4.4	6 28	0.2
Tu	12 54	4.4	19 00	1.0
7	0 56	4.1	7 18	0.5
W	13 39	4.3	20 03	1.1
8	1 39	3.8	8 14	0.6
Th	14 24	4.3	21 05	1.1
9	2 26	3.6	9 08	0.8
F	15 12	4.3	22 01	1.0
10	3 21	3.5	9 59	0.8
Sa	16 05	4.4	22 51	0.8
11	4 26	3.4	10 46	0.7
Su	17 00	4.6	23 39	0.6
12	5 27	3.5	11 33	0.7
M	17 49	4.8	. ..	. .
13	6 19	3.7	0 27	0.4
Tu	18 33	5.0	12 20	0.6
14	7 04	3.9	1 14	0.2
W	19 14	5.1	13 06	0.5
15	7 45	4.0	1 57	0.0
Th	19 53	5.3	13 52	0.3
16	8 25	4.2	2 38	-0.2
F	20 31	5.3	14 35	0.2
17	9 06	4.4	3 17	-0.3
Sa	21 12	5.2	15 16	0.1
18	9 50	4.5	3 53	-0.4
Su	21 56	5.1	15 57	0.1
19	10 37	4.7	4 29	-0.3
M	22 44	5.0	16 39	0.1
20	11 27	4.8	5 07	-0.2
Tu	23 36	4.8	17 27	0.2
21	. ..	. .	5 50	-0.1
W	12 18	4.9	18 26	0.4
22	0 28	4.5	6 42	0.1
Th	13 11	5.0	19 40	0.6
23	1 24	4.3	7 50	0.2
F	14 07	5.1	20 56	0.6
24	2 26	4.1	9 00	0.3
Sa	15 09	5.1	22 02	0.4
25	3 35	4.0	10 04	0.3
Su	16 17	5.2	23 01	0.2
26	4 49	4.0	11 03	0.2
M	17 22	5.3	23 57	0.0
27	5 55	4.2	. ..	. .
Tu	18 20	5.5	12 00	0.1
28	6 51	4.4	0 50	-0.2
W	19 10	5.6	12 55	0.0
29	7 40	4.6	1 40	-0.3
Th	19 57	5.5	13 47	-0.1
30	8 28	4.7	2 26	-0.4
F	20 41	5.4	14 36	-0.1
31	9 14	4.8	3 09	-0.5
Sa	21 25	5.2	15 21	0.0

AUGUST

Day	High Time	High Ht.	Low Time	Low Ht.
	h. m.	ft.	h. m.	ft.
1	9 59	4.7	3 [illegible]	-0.4
Su	22 08	4.9	16 [illegible]	[illegible]
2	10 44	4.7	4 27	[illegible]
M	22 50	4.6	16 43	[illegible]
3	11 28	4.6	5 03	0.0
Tu	23 32	4.3	17 25	0.7
4	. ..	. .	5 38	0.3
W	12 09	4.5	18 10	1.0
5	0 11	4.0	6 16	0.6
Th	12 50	4.4	19 08	1.2
6	0 51	3.8	7 04	0.9
F	13 31	4.3	20 17	1.3
7	1 35	3.6	8 10	1.1
Sa	14 17	4.3	21 21	1.2
8	2 30	3.4	9 16	1.1
Su	15 12	4.3	22 17	1.1
9	3 38	3.4	10 12	1.1
M	16 14	4.5	23 08	0.8
10	4 49	3.5	11 04	0.9
Tu	17 13	4.7	23 55	0.5
11	5 47	3.8	11 53	0.7
W	18 04	4.9	. ..	. .
12	6 35	4.1	0 41	0.3
Th	18 48	5.2	12 41	0.4
13	7 17	4.4	1 25	0.0
F	19 30	5.4	13 29	0.2
14	7 57	4.7	2 07	-0.3
Sa	20 10	5.4	14 14	-0.1
15	8 37	5.0	2 47	-0.4
Su	20 52	5.4	14 58	-0.2
16	9 21	5.2	3 26	-0.5
M	21 37	5.3	15 41	-0.3
17	10 09	5.3	4 04	-0.5
Tu	22 27	5.1	16 26	-0.2
18	11 02	5.3	4 43	-0.4
W	23 20	4.8	17 14	0.0
19	11 56	5.3	5 26	-0.1
Th	. ..	. .	18 11	0.3
20	0 16	4.5	6 19	0.2
F	12 53	5.2	19 23	0.5
21	1 14	4.2	7 30	0.4
Sa	13 52	5.1	20 40	0.6
22	2 19	4.0	8 47	0.6
Su	14 57	5.0	21 48	0.5
23	3 29	3.9	9 55	0.5
M	16 06	5.0	22 48	0.3
24	4 41	4.0	10 55	0.4
Tu	17 11	5.1	23 40	0.1
25	5 44	4.3	11 50	0.2
W	18 07	5.2	. ..	. .
26	6 37	4.6	0 30	-0.1
Th	18 55	5.3	12 42	0.1
27	7 23	4.8	1 17	-0.2
F	19 38	5.3	13 31	0.0
28	8 05	4.9	2 00	-0.3
Sa	20 19	5.2	14 17	0.0
29	8 45	5.0	2 40	-0.3
Su	20 57	5.0	14 59	0.0
30	9 24	4.9	3 19	-0.2
M	21 34	4.7	15 37	0.1
31	10 02	4.8	3 52	-0.1
Tu	22 10	4.5	16 15	0.3

SEPTEMBER

Day	High Time	High Ht.	Low Time	Low Ht.
	h. m.	ft.	h. m.	ft.
1	10 40	4.7	4 24	0.2
W	22 47	4.2	16 51	0.6
2	11 18	4.6	4 52	0.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	11 57	4.4	5 17	0.7
F	. ..	. .	18 13	1.1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sa	12 37	4.3	19 20	1.3
5	0 49	3.5	6 27	1.2
Su	13 23	4.3	20 38	1.3
6	1 45	3.4	8 21	1.4
M	14 18	4.3	21 41	1.1
7	2 56	3.4	9 38	1.2
Tu	15 24	4.4	22 33	0.9
8	4 10	3.6	10 35	1.0
W	16 31	4.6	23 21	0.6
9	5 13	4.0	11 26	0.6
Th	17 29	4.8	. ..	. .
10	6 02	4.4	0 06	0.2
F	18 19	5.1	12 16	0.3
11	6 46	4.8	0 49	-0.1
Sa	19 03	5.3	13 04	-0.1
12	7 27	5.2	1 32	-0.4
Su	19 46	5.4	13 51	-0.4
13	8 10	5.5	2 14	-0.6
M	20 30	5.4	14 36	-0.6
14	8 54	5.7	2 55	-0.6
Tu	21 16	5.2	15 24	-0.6
15	9 43	5.7	3 36	-0.6
W	22 08	5.0	16 11	-0.5
16	10 37	5.6	4 19	-0.5
Th	23 06	4.7	17 00	-0.2
17	11 36	5.4	5 06	-0.2
F	. ..	. .	17 57	0.1
18	0 07	4.4	6 01	0.2
Sa	12 36	5.2	19 07	0.4
19	1 09	4.1	7 16	0.6
Su	13 38	5.0	20 23	0.5
20	2 14	4.0	8 37	0.7
M	14 42	4.8	21 31	0.5
21	3 22	4.0	9 46	0.6
Tu	15 49	4.7	22 28	0.3
22	4 29	4.1	10 44	0.5
W	16 53	4.8	23 19	0.1
23	5 28	4.4	11 36	0.3
Th	17 47	4.8	. ..	. .
24	6 18	4.7	0 05	0.0
F	18 34	4.9	12 26	0.2
25	7 00	4.9	0 49	-0.1
Sa	19 15	4.9	13 11	0.0
26	7 38	5.1	1 30	-0.2
Su	19 53	4.8	13 54	0.0
27	8 15	5.1	2 09	-0.2
M	20 28	4.7	14 35	0.0
28	8 49	5.1	2 46	-0.1
Tu	21 02	4.5	15 13	0.1
29	9 23	4.9	3 20	0.1
W	21 35	4.2	15 48	0.2
30	9 55	4.8	3 50	0.3
Th	22 08	4.0	16 24	0.4

Time meridian 75° W. The hours of the day are numbered consecutively from 0^h (midnight) to 23^h (11 00 p.m.). 12^h is noon. All hours greater than 12 are in the afternoon (p.m.).

Heights are reckoned from the datum of soundings on charts of the locality which is mean low water.

Figure 11–32.—A page from the table of reference stations, table 1, tide tables.

Table 1 tells you that the height of high water at the reference station is 4.4 feet. From table 2, you learn that the height of high water at George Washington Bridge is 0.5 feet less than it is at the reference station. Therefore, height of high water at the bridge is 3.9 feet. Height of low water at New York is 1.1. Subtract this from 4.4 feet (height of high water) and you find that the range of the tide at the reference station is 3.3 feet.

Now turn to table 3, a table which makes it possible for you to find the height of the tide at any time. (See fig. 11–33.) You know that the duration of the fall in this case is 6 hours and 16 minutes and that the time from the nearest high water is 2 hours and 18 minutes past high water. The nearest value to 6 hours and 16 minutes is found to be 6 hours and 20 minutes. Enter the table on this line and run across to 2 hours and 19 minutes.

Now run down this column to the CORRECTION TO HEIGHT part of the table. You know that the range at the bridge is 3.3 feet. Where the 3.5 range line, the nearest range on the table to 3.3, intersects the TIME FROM THE NEAREST HIGH WATER column, read 1.0 feet. This is the amount the tide will have fallen below high by 1500, 2 hours and 18 minutes past high water. By subtracting this from the height of high water at the bridge (3.9 feet), you learn that 2.9 feet will be the approximate height of the tide above the charted depth at the bridge at 1500.

For some stations in table 2, height differences would give unsatisfactory predictions. In such cases, the height differences have been omitted and 1 or 2 ratios are given instead. Where 2 ratios are given, 1 in the HEIGHT OF HIGH WATER column and 1 in the HEIGHT OF LOW WATER column, the high waters and low waters at the reference station should be multiplied by these respective ratios. Where only one is given, the omitted ratio is either unreliable or unknown.

For certain stations, there is given in parentheses a ratio to be applied to the heights of high and low waters at the

Duration of rise or fall, see footnote	Time from the nearest high water or low water														
h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.	h. m.
4 00	0 08	0 16	0 24	0 32	0 40	0 48	0 56	1 04	1 12	1 20	1 28	1 36	1 44	1 52	2 00
4 20	0 09	0 17	0 26	0 35	0 43	0 52	1 01	1 09	1 18	1 27	1 35	1 44	1 53	2 01	2 10
4 40	0 09	0 19	0 28	0 37	0 47	0 56	1 05	1 15	1 24	1 33	1 43	1 52	2 01	2 11	2 20
5 00	0 10	0 20	0 30	0 40	0 50	1 00	1 10	1 20	1 30	1 40	1 50	2 00	2 10	2 20	2 30
5 20	0 11	0 21	0 32	0 43	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 47	1 57	2 08	2 19	2 29	2 40
5 40	0 11	0 23	0 34	[illegible]	0 57	1 08	1 19	1 31	1 42	[illegible]	2 05	2 16	2 27	2 39	2 50
6 00	0 12	[illegible]	0 36	0 48	1 00	1 12	1 24	1 36	1 48	2 00	[illegible]	2 24	2 36	2 48	3 00
6 20	[illegible]	0 25	0 38	0 51	1 03	1 16	1 29	1 41	1 54	2 0[illegible]	2 19	2 32	2 45	2 57	3 10
6 40	0 13	0 27	0 40	0 53	1 07	1 20	1 33	1 47	2 00	[illegible]	[illegible]	2 40	2 53	3 07	3 20
7 00	0 14	0 28	0 42	0 56	1 10	1 24	1 38	[illegible]	[illegible]	2 20	2 34	2 48	3 02	3 16	3 30
7 20	0 15	0 29	0 44	0 59	1 13	1 28	[illegible]	[illegible]	2 12	2 27	2 41	2 56	3 11	3 25	3 40
7 40	0 15	0 31	0 46	1 01	1 17	1 32	[illegible]	2 03	2 18	2 33	2 49	3 04	3 19	3 35	3 50
8 00	0 16	0 32	0 48	1 04	[illegible]	[illegible]	1 52	2 08	2 24	2 40	2 56	3 12	3 28	3 44	4 00
8 20	0 17	0 33	0 50	1 07	[illegible]	1 40	1 57	2 13	2 30	2 47	3 03	3 20	3 37	3 53	4 10
8 40	0 17	0 35	0 52	[illegible]	1 27	1 44	2 01	2 19	2 36	2 53	3 11	3 28	3 45	4 03	4 20
9 00	0 18	0 36	[illegible]	1 12	1 30	1 48	2 06	2 24	2 42	3 00	3 18	3 36	3 54	4 12	4 30
9 20	0 19	0 37	[illegible]	1 15	1 33	1 52	2 11	2 29	2 48	3 07	3 25	3 44	4 03	4 21	4 40
9 40	0 19	[illegible]	0 58	1 17	1 37	1 56	2 15	2 35	2 54	3 13	3 33	3 52	4 11	4 31	4 50
10 00	0 20	[illegible]	1 00	1 20	1 40	2 00	2 20	2 40	3 00	3 20	3 40	4 00	4 20	4 40	5 00
10 20	0 21	[illegible]	1 02	1 23	1 43	2 04	2 25	2 45	3 06	3 27	3 47	4 08	4 29	4 49	5 10
10 40	[illegible]	0 43	1 04	1 25	1 47	2 08	2 29	2 51	3 12	3 33	3 55	4 16	4 37	4 59	5 20

Range of tide, see footnote	Correction to height														
Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.
0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
1.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5
1.5	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8
2.0	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
[illegible]	0.0	0.0	0.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.5	0.6	0.7	0.9	1.0	1.1	1.2
[illegible]	[illegible]	[illegible]	0.1	0.1	0.2	0.3	0.4	0.5	[illegible]	[illegible]	[illegible]	1.0	1.2	1.3	1.5
3.5	[illegible]	0.0	0.1	0.2	0.2	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.8
[illegible]	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.7	0.8	1.0	[illegible]	1.4	1.6	1.8	2.0
4.5	0.0	0.0	0.1	0.2	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2
5.0	0.0	0.1	0.1	0.2	0.3	0.5	0.6	0.8	1.0	1.2	1.5	1.7	2.0	2.2	2.5
5.5	0.0	0.1	0.1	0.2	0.4	0.5	0.7	0.9	1.1	1.4	1.6	1.9	2.2	2.5	2.8
6.0	0.0	0.1	0.1	0.3	0.4	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.0
6.5	0.0	0.1	0.2	0.3	0.4	0.6	0.8	1.1	1.3	1.6	1.9	2.2	2.6	2.9	3.2
7.0	0.0	0.1	0.2	0.3	0.5	0.7	0.9	1.2	1.4	1.8	2.1	2.4	2.8	3.1	3.5
7.5	0.0	0.1	0.2	0.3	0.5	0.7	1.0	1.2	1.5	1.9	2.2	2.6	3.0	3.4	3.8
8.0	0.0	0.1	0.2	0.3	0.5	0.8	1.0	1.3	1.6	2.0	2.4	2.8	3.2	3.6	4.0
8.5	0.0	0.1	0.2	0.4	0.6	0.8	1.1	1.4	1.8	2.1	2.5	2.9	3.4	3.8	4.2
9.0	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.5	1.9	2.2	2.7	3.1	6.6	4.0	4.5
9.5	0.0	0.1	0.2	0.4	0.6	0.9	1.2	1.6	2.0	2.4	2.8	3.3	3.8	4.3	4.8
10.0	0.0	0.1	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	3.0	3.5	4.0	4.5	5.0
10.5	0.0	0.1	0.3	0.5	0.7	1.0	1.3	1.7	2.2	2.6	3.1	3.6	4.2	4.7	5.2
11.0	0.0	0.1	0.3	0.5	0.7	1.1	1.4	1.8	2.3	2.8	3.3	3.8	4.4	4.9	5.5
11.5	0.0	0.1	0.3	0.5	0.8	1.1	1.5	1.9	2.4	2.9	3.4	4.0	4.6	5.1	5.8
12.0	0.0	0.1	0.3	0.5	0.8	1.1	1.5	2.0	2.5	3.0	3.6	4.1	4.8	5.4	6.0
12.5	0.0	0.1	0.3	0.5	0.8	1.2	1.6	2.1	2.6	3.1	3.7	4.3	5.0	5.6	6.2
13.0	0.0	0.1	0.3	0.6	0.9	1.2	1.7	2.2	2.7	3.2	3.9	4.5	5.1	5.8	6.5
13.5	0.0	0.1	0.3	0.6	0.9	1.3	1.7	2.2	2.8	3.4	4.0	4.7	5.3	6.0	6.8
14.0	0.0	0.2	0.3	0.6	0.9	1.3	1.8	2.3	2.9	3.5	4.2	4.8	5.5	6.3	7.0
14.5	0.0	0.2	0.4	0.6	1.0	1.4	1.9	2.4	3.0	3.6	4.3	5.0	5.7	6.5	7.2
15.0	0.0	0.2	0.4	0.6	1.0	1.4	1.9	2.5	3.1	3.8	4.4	5.2	5.9	6.7	7.5
15.5	0.0	0.2	0.4	0.7	1.0	1.5	2.0	2.6	3.2	3.9	4.6	5.4	6.1	6.9	7.8
16.0	0.0	0.2	0.4	0.7	1.1	1.5	2.1	2.6	3.3	4.0	4.7	5.5	6.3	7.2	8.0
16.5	0.0	0.2	0.4	0.7	1.1	1.6	2.1	2.7	3.4	4.1	4.9	5.7	6.5	7.4	8.2
17.0	0.0	0.2	0.4	0.7	1.1	1.6	2.2	2.8	3.5	4.2	5.0	5.9	6.7	7.6	8.5
17.5	0.0	0.2	0.4	0.8	1.2	1.7	2.2	2.9	3.6	4.4	5.2	6.0	6.9	7.8	8.8
18.0	0.0	0.2	0.4	0.8	1.2	1.7	2.3	3.0	3.7	4.5	5.3	6.2	7.1	8.1	9.0
18.5	0.1	0.2	0.5	0.8	1.2	1.8	2.4	3.1	3.8	4.6	5.5	6.4	7.3	8.3	9.2
19.0	0.1	0.2	0.5	0.8	1.3	1.8	2.4	3.1	3.0	4.8	5.6	6.6	7.5	8.5	9.5
19.5	0.1	0.2	0.5	0.8	1.3	1.9	2.5	3.2	4.0	4.9	5.8	6.7	7.7	8.7	9.8
20.0	0.1	0.2	0.5	0.9	1.3	1.9	2.6	3.3	4.1	5.0	5.9	6.9	7.9	9.0	10.0

Obtain from the predictions the high water and low water, one of which is before and the other after the time for which the height is required. The difference between the times of occurrence of these tides is the duration of rise or fall, and the difference between their heights is the range of tide for the above table. Find the difference between the nearest high or low water and the time for which the height is required.

Enter the table with the duration of rise or fall, printed in heavy-faced type, which most nearly agrees with the actual value, and on that horizontal line find the time from the nearest high or low water which agrees most nearly with the corresponding actual difference. The correction sought is in the column directly below, on the line with the range of tide.

When the nearest tide is high water, subtract the correction.

When the nearest tide is low water, add the correction.

Figure 11–33.—Height of Tide at Any Time, table 3, tide tables.

reference station and a correction in feet to be applied to that product. As an example, in table 2, opposite Hare Bay, No. 144, the values in the HEIGHT DIFFERENCE column are (0.68+1.9 feet) referred to Argentia. On a given morning the heights of high and low waters at Argentia are 6.7 and −0.3 feet, respectively. The predicted heights for Hare Bay are obtained as follows:

Argentia	6.7	feet high water	−0.3	foot low water
	×0.68	(ratio)	×0.68	(ratio)
	4.6		−0.2	
	+1.9	(correction)	+1.9	(correction)
Hare Bay	6.5	feet high water	1.7	feet low water

The MEAN RANGE is the difference in height between mean high water and mean low water. The SPRING RANGE is the average semidiurnal range occurring semimonthly as the result of the moon being new or full. It is larger than the mean range where the type of tide is either semidiurnal or mixed, and is of no practical significance where the type of tide is diurnal. Where the tide is chiefly of the diurnal type the table gives the diurnal range, which is the difference in height between mean higher high water and mean lower low water.

For stations where the tide is chiefly diurnal, the time differences and the height of differences and ratios are intended primarily for predicting the higher high and lower low waters. When the lower high water and the higher low water at the reference station are nearly the same height, the corresponding tides often cannot be obtained satisfactorily by means of the tidal differences.

CURRENT TABLES

A tidal current is the result of a tide, but not the tide itself. Tidal current is the horizontal motion of water resulting from the vertical motion caused by tide. Tidal currents are so called to distinguish them from ocean or river currents.

The horizontal motion of water toward the land caused by a rising tide is called FLOOD CURRENT; the horizontal motion away from the land caused by a falling tide, EBB CURRENT. Between these two, while the current is changing direction, there is a brief period when no horizontal motion is perceptible. This is called SLACK WATER.

The change of direction of the current always lags behind the time of turning of the tide, by an interval which varies in length according to the physical characteristics of the land around the body of tidewater. For instance, along a relatively straight coast with only shallow indentations, there is usually little difference between the time of high or low water and the time of slack water. But where a large bay connects with the ocean through a narrow channel, the tide and the current may be out of phase by as much as 3 hours. In a case like this, the current in the channel may be running at its greatest velocity when it is high or low water outside. The direction of a tidal current is called SET and the velocity is called DRIFT.

Reading Current Tables

Current tables are published annually by the Coast and Geodetic Survey. Like the tide tables, they are divided into a table for reference stations (table 1) and a table for subordinate stations (table 2). Table 1 lists predicted times of slack water and predicted times and velocities of maximum flood and ebb at the reference stations for each day of the year.

In table 2, the latitude and longitude of each subordinate station are given, together with difference in time of current and a velocity ratio with respect to one of the reference stations. Like the tidal difference in time, the current time difference is applied to the time of slack or strength at the reference station to get the corresponding time at the subordinate station. Velocity at the subordinate station is found by multiplying velocity at the reference station by the listed velocity ratio.

Also included in table 2 is information concerning flood interval, flood direction, average velocity, and spring velocity at strength of current. As you know, the flood tide is caused by the moon's attraction. In other words, as the moon passes over the meridian, the water piles up in its wake, as it were. The flood interval is the time which elapses between the moon's meridian transit and the ensuing maximum flood current. Maximum ebb will occur approximately 6¼ hours earlier or later.

Flood direction is the true direction of the set of the current at maximum flood. The set of maximum ebb is generally pretty close to the reciprocal of the flood direction.

Average velocity given is the mean of all maximum flood and ebb currents. Spring velocity is the mean of the strength of flood and ebb currents at the time of spring tides.

Table 3 in the current tables is like table 3 in the tide tables. It is used to find the velocity of the current at a specific time.

Now, let's see if we can determine the set and drift of the current at the George Washington Bridge, for the same time (1500) on the same day for which we predicted the height of the tide. First, find George Washington Bridge in table 2 of the *Current Tables, Atlantic Coast, North America.* The page from this table in the 1954 volume is shown in figure 11–34. Note that the current reference station for George Washington Bridge is The Narrows, shown in boldface type near the top of the page.

Now notice that the time difference shown opposite is plus 1 hour and 55 minutes. This means that when certain current conditions exist at The Narrows, the same conditions will exist 1 hour and 55 minutes later at the bridge. Velocity ratio, as you see, is 1.1. This means that, if the current flows at a certain rate at The Narrows, it will be flowing 1.1 times as fast at the bridge 1 hour and 55 minutes later.

Under the heading AT STRENGTH OF CURRENT, you see four columns. The first is FLOOD INTERVAL. This, as already explained, is the average number of hours and minutes after

Station or locality	Latitude	Longitude	Time difference	Velocity ratio	At strength of current: Flood interval	Flood direction (true)	Average velocity	Spring velocity
	° ′ North	° ′ West	h. m.		h. m.	Deg.	Knots	Knots
Long Island, South Coast			*Time meridian, 75° W.*					
Reference station, **The Narrows,** New York Harbor, p. 52								
Fire Island Lighted Whistle Buoy 2FI*	40 29	73 11	------	------	------	------	------	------
Fire Island Inlet, 22 miles south of [1]	40 16	73 16	------	------	------	------	------	------
Shinnecock Canal, railroad bridge	40 53	72 30	[2] −0 40	[2] 0.8	------	[2] 180	[2] 1.5	------
Ponquogue bridge, Shinnecock Bay	40 51	72 30	+0 40	0.4	7 40	250	0.7	0.8
Shinnecock Inlet	40 51	72 29	−0 20	1.3	6 30	350	2.4	2.9
Fire Island Inlet, inside, near Democrat Pt	40 38	73 17	−0 20	1.3	6 35	115	2.3	2.8
Jones Inlet	40 35	73 34	−1 00	1.6	5 55	35	2.9	3.5
Long Beach, inside, between bridges	40 36	73 40	0 00	0.3	6 55	75	0.6	0.7
East Rockaway Inlet	40 35	73 45	−1 30	1.3	5 25	40	2.3	2.8
Ambrose Channel Lightship*	40 27	73 49	------	------	------	------	------	------
Scotland Lightship*	40 27	73 55	------	------	------	------	------	------
Jamaica Bay								
Rockaway Inlet	40 34	73 56	−2 00	1.2	4 55	85	2.2	2.6
East of Barren Island	40 35	73 53	−2 10	0.8	4 40	5	1.5	1.8
Canarsie (midchannel, off pier)	40 38	73 53	−1 45	0.3	5 10	45	0.6	0.7
Beach Channel (bridge)	40 35	73 49	−1 20	1.1	5 35	60	1.9	2.3
Grass Hassock Chan., off Little Bay Marsh	40 37	73 47	−1 05	0.6	5 50	50	1.0	1.2
New York Harbor Entrance								
Ambrose Channel entrance	40 30	73 58	−1 05	1.1	5 45	300	2.0	2.4
Ambrose Channel, SE. of West Bank Light	40 32	74 01	(3)	0.8	5 55	310	1.5	1.8
Ambrose Channel, north end	40 34	74 02	+0 10	0.9	7 05	330	1.6	1.9
Coney Island, ¼ mile west of	40 35	74 01	−0 55	0.9	6 00	330	1.7	2.0
Ft. Lafayette, channel east of	40 36	74 02	[4] −2 00	0.6	6 50	345	1.0	1.2
The Narrows, midchannel	40 37	74 03	------	------	6 55	340	1.8	2.2
Upper Bay, New York Harbor								
Tompkinsville	40 38	74 04	+0 05	1.0	6 55	5	1.8	2.2
Bay Ridge Channel	40 39	74 02	−0 40	0.6	6 15	40	1.1	1.3
Red Hook Channel	40 40	74 01	−0 30	0.7	6 25	10	1.2	1.4
Robbins Reef Light, east of	40 39	74 03	+0 15	0.8	7 05	15	1.5	1.8
Red Hook, 1 mile west of	40 41	74 02	+0 50	1.0	7 45	25	1.8	2.2
Statue of Liberty, east of	40 42	74 02	+0 55	1.1	7 50	30	2.0	2.4
Hudson River, Midchannel [5]								
The Battery, northwest of	40 43	74 02	+1 35	1.1	8 25	15	1.9	2.3
Desbrosses Street	40 43	74 01	+1 35	1.1	8 30	10	1.9	2.3
Chelsea Docks	40 45	74 01	+1 35	1.1	8 35	10	1.9	2.3
Forty-second Street	40 46	74 00	+1 40	1.1	8 40	30	2.0	2.4
Ninety-sixth Street	40 48	73 59	+1 45	1.1	8 45	30	2.0	2.4
George Washington Bridge	40 51	73 57	+1 55	1.1	8 45	20	1.9	2.3
Riverdale	40 54	73 55	+2 15	0.9	9 05	15	1.7	2.0
Dobbs Ferry	41 01	73 53	+2 35	0.8	9 30	10	1.5	1.8

*See table 5.

[1] Tidal current is weak averaging about 0.1 knot at maximum.

[2] For maximum southward current only, the gates of the lock being closed to prevent northward flow. Apply difference and ratio to maximum ebb at The Narrows.

[3] Current is rotary, turning clockwise. Time difference for maximum flood, $-1^h\ 00^m$; maximum ebb, $+0^h\ 15^m$ (direction 170°). Minimum current of 0.9 knot sets SW. about time of "Slack, flood begins" at The Narrows. Minimum current of 0.5 knot sets NE. about 1 hour before "Slack, ebb begins" at The Narrows.

[4] Time difference for maximum ebb and beginning of flood. Maximum flood and beginning of ebb occur about the same time as in The Narrows.

[5] The values for the Hudson River are for the summer months, when the fresh-water discharge is a minimum.

Figure 11–34.—Current differences and constants, table 2, current tables.

the moon transits the meridian that maximum flood current will occur. Maximum ebb will be 6 hours later or earlier.

Direction (or set) of the flood current (20° true) is given in the next column. Unless the tables state otherwise, you can assume that direction of the ebb current will be the reciprocal (180° plus) of this. The next column gives average velocity and the last column spring velocity.

You now have all the values you must apply to the reference station data in order to determine conditions at the subordinate station. These are:

Time difference: plus 1h 55m.
Velocity ratio: 1.1.
Flood direction: 20° true.

Turn to table 1, The Narrows, and find Friday, 3 September, as shown in figure 11–35. You want to know the set (direction) and the drift (velocity) of the current at George Washington Bridge at 1500. First, is the current ebbing or flowing at this time? Ebbing begins at the reference station at 1344, and the difference is plus 1 hour 55 minutes. Consequently, ebbing begins at the bridge at 1344 plus 1 hour 55 minutes, or 1539. So at 1500 the current is still flooding. The interval between maximum current and slack is 3 hours and 8 minutes, and the interval between 1500 and slack is 39 minutes. Velocity of the maximum ebb at the reference station is 1.7 knots, and the velocity ratio at the bridge is 1.1 times that, or 1.87.

Now turn to table 3, shown in figure 11–36, and figure out the velocity of the current at the bridge at 1500. You enter the table with the interval between slack and minimum current (3h 9m) and the interval between slack and minimum current (39m). The value in the column headings of the table which is closest to the first is 3 hours and no minutes (3h 00m); the value closest to the second in the left-hand column is 40 minutes (0h 40m). Where these two lines in the table intersect, you find the value 0.3. Multiply the velocity of the maximum ebb current (1.87 knots) by this

SEPTEMBER

Day	Slack, Flood Begins	Maximum Flood		Slack; Ebb Begins	Maximum Ebb	
	Time	Time	Velocity	Time	Time	Velocity
	h. m.	h. m.	kn.	h. m.	h. m.	kn.
1	[illegible]	9 01	1.7	. ..	3 04	2.0
W	[illegible]	21 23	1.3	12 15	15 29	1.9
2	[illegible]	9 47	1.6	0 24	3 41	1.8
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	8 01	10 35	1.5	1 05	4 22	1.7
F	20 59	23 00	1.1	13 44	17 00	1.6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sa	21 55	23 50	1.0	14 33	17 57	1.5
5	9 49	. ..	. .	2 39	6 08	1.4
Su	22 52	12 13	1.4	15 27	19 02	1.5
6	10 43	0 41	0.9	3 36	7 14	1.4
M	23 45	13 04	1.4	16 27	20 00	1.6
7	11 40	1 38	0.9	4 38	8 13	1.5
Tu	. ..	14 01	1.4	17 26	20 52	1.7
8	0 36	2 39	1.0	5 39	9 05	1.6
W	12 32	15 01	1.5	18 21	21 40	1.8
9	1 24	3 37	1.2	6 34	9 53	1.8
Th	13 26	16 00	1.7	19 09	22 25	2.0
10	2 08	4 30	1.5	7 23	10 40	2.0
F	14 17	16 51	1.8	19 54	23 11	2.1
11	2 49	5 14	1.8	8 11	11 30	2.2
Sa	15 04	17 36	2.0	20 38	23 58	2.3
12	3 28	5 57	2.0	8 58	. ..	. .
Su	15 50	18 18	2.1	21 22	12 19	2.4
13	4 07	6 37	2.2	9 45	0 42	2.4
M	16 35	19 02	2.1	22 07	13 08	2.5
14	4 46	7 22	2.3	10 34	1 28	2.4
Tu	17 22	19 47	2.0	22 52	13 56	2.6
15	5 29	8 09	2.3	11 24	2 12	2.4
W	18 13	20 37	1.9	23 41	14 43	2.6
16	6 16	9 00	2.2	. ..	2 57	2.4
Th	19 09	21 31	1.7	12 15	15 31	2.5
17	7 10	9 57	2.1	0 30	3 45	2.2
F	20 10	22 28	1.5	13 08	16 25	2.3
18	8 12	10 54	2.0	1 22	4 37	2.0
Sa	21 15	23 26	1.4	14 04	17 25	2.1
19	9 18	11 53	1.8	2 18	5 41	1.8
Su	22 19	. ..	. .	15 04	18 34	1.9
20	10 22	0 26	1.3	3 21	6 52	1.7
M	23 18	12 52	1.7	16 09	19 42	1.9
21	11 25	1 33	1.2	4 28	8 02	1.7
Tu	. ..	14 02	1.6	17 16	20 43	1.9
22	0 15	2 54	1.3	5 36	9 03	1.8
W	12 27	15 23	1.6	18 16	21 36	2.0
23	1 09	4 02	1.4	6 37	9 56	1.9
Th	13 25	16 25	1.7	19 08	22 25	2.0
24	1 58	4 55	1.6	7 29	10 46	2.0
F	14 18	17 15	1.7	19 53	23 11	2.0
25	2 44	5 35	1.7	8 15	11 36	2.0
Sa	15 08	17 53	1.7	20 34	23 55	2.0
26	3 25	6 09	1.8	8 58	. ..	. .
Su	15 52	18 24	1.7	21 14	12 21	2.1
27	4 04	6 37	1.9	9 39	0 37	2.0
M	16 34	18 54	1.6	21 53	13 04	2.1
28	4 41	7 09	1.8	10 20	1 18	2.0
Tu	17 16	19 30	1.5	22 32	13 45	2.1
29	5 18	7 45	1.8	11 01	1 55	1.9
W	17 59	20 08	1.4	23 12	14 25	2.0
30	5 54	8 25	1.7	11 44	2 33	1.9
Th	18 44	20 52	1.2	23 52	15 04	2.0

OCTOBER

Day	Slack; Flood Begins	Maximum Flood		Slack; Ebb Begins	Maximum Ebb	
	Time	Time	Velocity	Time	Time	Velocity
	h. m.	h. m.	kn.	h. m.	h. m.	kn.
1	6 34	9 11	1.6	. ..	3 10	1.7
F	19 34	21 41	1.1	12 26	15 43	1.9
2	7 18	10 00	1.5	0 34	3 48	1.6
Sa	20 29	22 31	1.0	13 11	16 26	1.7
3	8 12	10 49	1.5	1 20	4 33	1.5
Su	21 25	23 22	1.0	13 58	17 19	1.6
4	9 10	11 40	1.4	2 10	5 28	1.4
M	22 18	. ..	. .	14 50	18 20	1.5
5	10 11	0 12	1.0	3 04	6 36	1.4
Tu	23 08	12 32	1.4	15 46	19 22	1.6
6	11 08	1 05	1.1	4 06	7 39	1.5
W	23 55	13 27	1.4	16 44	20 16	1.7
7	. ..	2 00	1.2	5 09	8 35	1.7
Th	12 04	14 24	1.5	17 41	21 04	1.9
8	0 41	2 58	1.4	6 06	9 25	1.9
F	12 59	15 24	1.6	18 33	21 51	2.0
9	1 25	3 52	1.7	6 58	10 14	2.1
Sa	13 51	16 20	1.8	19 21	22 35	2.2
10	2 08	4 42	2.0	7 46	11 03	2.3
Su	14 42	17 10	1.9	20 06	23 22	2.3
11	2 51	5 28	2.2	8 34	11 54	2.5
M	15 30	17 55	2.0	20 53	. ..	. .
12	3 34	6 13	2.4	9 22	0 11	2.4
Tu	16 19	18 39	2.0	21 39	12 45	2.6
13	4 18	6 58	2.5	10 13	1 00	2.4
W	17 07	19 26	2.0	22 28	13 36	2.7
14	5 03	7 47	2.4	11 04	1 49	2.4
Th	17 58	20 16	1.8	23 18	14 26	2.6
15	5 52	8 38	2.3	11 56	2 37	2.3
F	18 53	21 11	1.7	. ..	15 15	2.5
16	6 48	9 35	2.1	0 11	3 27	2.2
Sa	19 54	22 11	1.6	12 49	16 07	2.3
17	7 52	10 34	2.0	1 07	4 21	2.0
Su	20 55	23 12	1.4	13 44	17 05	2.1
18	8 59	11 33	1.8	2 05	5 23	1.8
M	21 55	. ..	. .	14 42	18 10	1.9
19	10 06	0 13	1.4	3 06	6 34	1.7
Tu	22 52	12 33	1.6	15 42	19 16	1.9
20	11 08	1 18	1.4	4 12	7 43	1.7
W	23 45	13 39	1.5	16 45	20 18	1.9
21	. ..	2 29	1.4	5 19	8 45	1.8
Th	12 08	14 54	1.4	17 43	21 09	1.9
22	0 36	3 33	1.5	6 19	9 36	1.9
F	13 04	15 59	1.4	18 35	21 55	1.9
23	1 26	4 26	1.6	7 09	10 23	1.9
Sa	13 59	16 50	1.5	19 21	22 38	1.9
24	2 10	5 08	1.8	7 53	11 10	2.0
Su	14 47	17 31	1.5	20 01	23 21	1.9
25	2 53	5 41	1.8	8 33	11 55	2.0
M	15 34	18 01	1.5	20 41	. ..	. .
26	3 32	6 10	1.9	9 13	0 04	1.9
Tu	16 15	18 31	1.4	21 21	12 39	2.0
27	4 10	6 41	1.9	9 53	0 45	1.8
W	16 58	19 04	1.4	22 01	13 20	2.0
28	4 46	7 16	1.8	10 34	1 27	1.8
Th	17 40	19 42	1.3	22 41	14 00	2.0
29	5 21	7 56	1.8	11 15	2 05	1.7
F	18 23	20 25	1.2	23 25	14 40	2.0
30	5 59	8 40	1.7	11 58	2 43	1.7
Sa	19 10	21 13	1.1	. ..	15 19	1.9
31	6 42	9 28	1.6	0 08	3 22	1.6
Su	20 00	22 04	1.1	12 42	16 01	1.8

Time meridian 75° W. The hours of the day are numbered consecutively from 0^h (midnight) to 23^h (11 00 p.m.). 12^h is noon. All hours greater than 12 are in the afternoon (p.m.).
On the flood the current sets northward; on the ebb, southward.

Figure 11–35.—Predictions for reference station, table 1, current tables.

TABLE A.—TIDAL CURRENT

Interval between slack and desired time	Interval between slack and maximum current											
	h. m. 1 40	h. m. 2 00	h. m. 2 20	h. m. 2 40	h. m. 3 00	h. m. 3 20	h. m. 3 40	h. m. 4 00	h. m. 4 20	h. m. 4 40	h. m. 5 00	h. m. 5 20
	f.	f.	f.	f.	[illegible]	f.	f.	f.	f.	f.	f.	f.
[illegible]	0.3	0.3	0.2	0.2	[illegible]	0.2	0.1	0.1	0.1	0.1	0.1	0.1
0 40	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2
[illegible]	0.8	[illegible]	[illegible]	[illegible]	[illegible]	0.5	0.4	0.4	0.4	0.3	0.3	0.3
1 20	1.0	0.9	0.8	0.7	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4
1 40	1.0	1.0	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.5	C.5	0.5
2 00	------	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.6	0.6	0.6
2 20	------	------	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7	0.7	0.6
2 40	------	------	------	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.7	0.7
3 00	------	------	------	------	1.0	1.0	1.0	0.9	0.9	0.8	0.8	0.8
3 20	------	------	------	------	------	1.0	1.0	1.0	0.9	0.9	0.9	0.8
3 40	------	------	------	------	------	------	1.0	1.0	1.0	0.9	0.9	0.9
4 00	------	------	------	------	------	------	------	1.0	1.0	1.0	1.0	0.9
4 20	------	------	------	------	------	------	------	------	1.0	1.0	1.0	1.0
4 40	------	------	------	------	------	------	------	------	------	1.0	1.0	1.0
5 00	------	------	------	------	------	------	------	------	------	------	1.0	1.0
5 20	------	------	------	------	------	------	------	------	------	------	------	1.0

TABLE B.—HYDRAULIC CURRENT

Interval between slack and desired time	Interval between slack and maximum current											
	h. m. 1 40	h. m. 2 00	h. m. 2 20	h. m. 2 40	h. m. 3 00	h. m. 3 20	h. m. 3 40	h. m. 4 00	h. m. 4 20	h. m. 4 40	h. m. 5 00	h. m. 5 20
h. m.	f.	f.	f.	f.	f.	f.	f.	f.	f.	f.	f.	f.
0 20	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3
0 40	0.8	0.7	0.7	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.4
1 00	0.9	0.8	0.8	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5
1 20	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.6	0.6
1 40	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7
2 00	------	1.0	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7
2 20	------	------	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8
2 40	------	------	------	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.8
3 00	------	------	------	------	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
3 20	------	------	------	------	------	1.0	1.0	1.0	1.0	0.9	0.9	0.9
3 40	------	------	------	------	------	------	1.0	1.0	1.0	1.0	1.0	0.9
4 00	------	------	------	------	------	------	------	1.0	1.0	1.0	1.0	1.0
4 20	------	------	------	------	------	------	------	------	1.0	1.0	1.0	1.0
4 40	------	------	------	------	------	------	------	------	------	1.0	1.0	1.0
5 00	------	------	------	------	------	------	------	------	------	------	1.0	1.0
5 20	------	------	------	------	------	------	------	------	------	------	------	1.0

Use Table A for all places except those listed below for Table B.
Use Table B for Cape Cod Canal, Hell Gate, Chesapeake and **Delaware Canal and all stations in Table 2 which are referred to them.**

1. From predictions find the time of slack water and the time and velocity of maximum current (flood or ebb), one of which is immediately before and the other after the time for which the velocity is desired.
2. Find the interval of time between the above slack and maximum current, and enter the top of Table A or B with the interval which most nearly agrees with this value.
3. Find the interval of time between the above slack and the time desired, and enter the side of Table A or B with the interval which most nearly agrees with this value.
4. Find, in the table, the factor corresponding to the above two intervals and multiply the maximum velocity by this factor. The result will be the approximate velocity at the time desired.

Figure 11–36.—Velocity of current at any time, table 3, current tables.

factor and you get 0.561. This is the velocity (drift) of the current at 1500.

What is the direction, or set? Well, you know that the current is still flooding at this time, and flood direction is 20°. Direction of the ebb will be 180° plus 20°, or 200°, the reciprocal of 20 degrees.

QUIZ

1. The basic difference between plane and geodetic surveys can be expressed in terms of what?
2. What are the three types of surveys with which you are most likely to come in contact?
3. What unit of measurement is used in the United States as a basis for field measurements?
4. How are fractions of a foot expressed?
5. In third order surveys what is the nearest fraction of a foot which should not be exceeded in order to keep the survey to the necessary accuracy?
6. How is the term STATION used in surveys?
7. When are measurements expressed in yards?
8. How are stadia measurements read?
9. In stadia measurements when the line of sight of the instrument is inclined upward or downward, what value becomes one of the factors necessary to reduce stadia readings to horizontal distances?
10. What is an isogonic chart?
11. What is the purpose of leveling?
12. What is differential leveling?
13. What is trigonometric leveling used for?
14. How is traversing defined?
15. What is a plane table?
16. How is a plane table set up?
17. Profiles are usually plotted for what purposes?
18. What are cross sections used for?
19. What projections are used with the State Coordinate System?
20. What are rectangular coordinates?

21. (a) What is the difference in latitude called in the rectangular coordinate system? (b) The difference in longitude?

22. What methods are used in plotting horizontal control?

23. When is the protractor and scale method used?

24. What is the only practical and satisfactory method for plotting the positions of control stations in any system of horizontal control?

25. (a) What is the tidal datum for Navy installations on the Atlantic and Gulf coasts? (b) For the Pacific coast? (c) For continental leveling?

26. (a) When do spring tides occur? (b) Neap tides?

27. What is a tidal current?

28. (a) What is the direction of the tidal current called? (b) The velocity?

CHAPTER 12

LETTERING

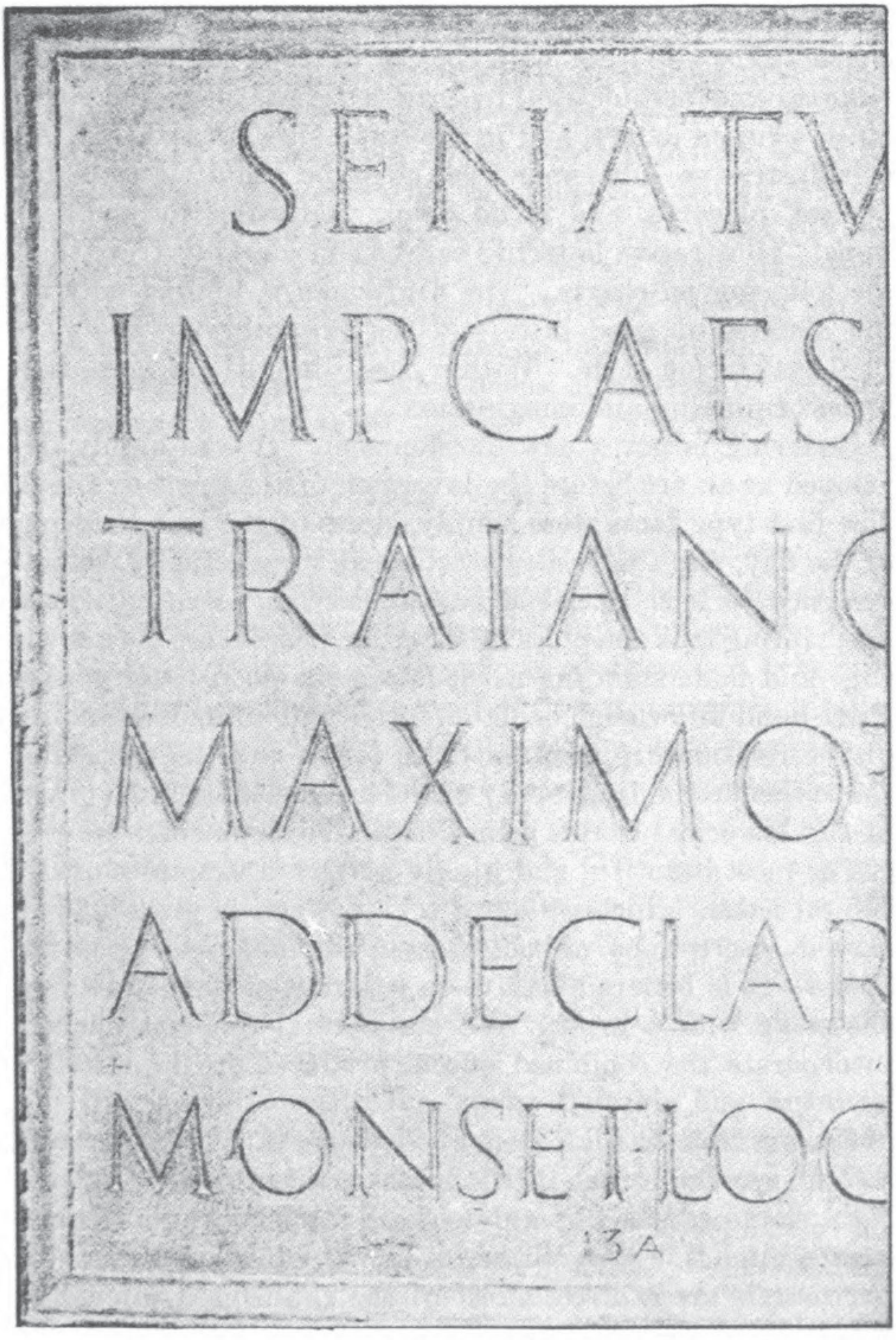
INTRODUCTION

Lettering is an art. Like other arts, it requires years of study and practice. You will never be a good lettering man until you know what makes one alphabet easier to read than another, and what gives one more beauty and character than another. You should be able to see good letter forms in your mind.

But an understanding of letters and the ability to think them must be accompanied by practice in drawing them until the muscles of your hand learn the pattern of the strokes. You should be able to draw perfect letters without consciously thinking of this pattern. In order to be a top-notch lettering man, you need good taste, an ability to visualize, and highly trained hand muscles.

If you have mastered the single-stroke gothic alphabet, you have made a good start in lettering. This alphabet is the skeleton for most of the lettering you will be required to execute. You will find that the order and direction of the strokes are very much the same, and the added strokes necessary for other alphabets fit naturally into the pattern. Built-up letters, for which the outlines are first drawn and then filled in, follow no such pattern of strokes, but the skeletons of the letters are still the same. The single-stroke gothic alphabet, the order of the strokes, the use of guide lines, and the spacing are discussed in chapter 5, *Draftsman 3*, NavPers 10471.

In the engineering drafting fields, you will have little need to know how to do any other type of lettering. As a topo-



Courtesy Sir Isaac Pitman & Sons Ltd., London, and Pitman Publishing Corporation, New York

Figure 12–1.—Portion of an inscription on base of Trajan Column, Rome, *circa* 114 A. D.

graphic or lithographic draftsman, you should be prepared to execute lettering which matches the lettering on maps or charts. Usually this will consist of type-set letters. It requires considerable skill to draw letters as clean and regular as printed letters, and in the small sizes often used. As an illustrative draftsman, you will be required to letter posters, placards, and to do display lettering for publications. Illustrative lettering can be considerably freer than the lettering on charts. The draftsman is limited only by the dictates of good taste and the suitability of the particular lettering style. Within these limitations, he is free to use originality and imagination.

Lettering is not a new development. It was highly developed as an art before the invention of the printing press. The first type faces were simply copies of the best lettering of the day, and the first printed books were actually frauds, designed to look like, and be sold as, hand-written books. As printing took the place of lettering, people lost the knowledge and understanding needed to make good letter forms. First-hand knowledge of letter forms and an understanding of the relationship between these forms and the tools that shape them come from study of the finest models and a grasp of the historical causes behind their development.

The most beautiful and highly perfected examples of the capital letters which we know today as roman are found in carved inscriptions on old Roman monuments. (See fig. 12–1.) It is believed that these letters were first drawn on the stone with a brush. All our normal roman alphabets incorporate the combined effects produced in these letters by brush and chisel.

For example, the left stem of the letter A was drawn with a light upward stroke of the brush and is thinner than the right stem produced by a downward stroke with more pressure behind it. Also the serifs at the end of the stems or horizontals are a direct effect of the chisel used in cutting the letters. The picture of these letters has become so firmly our idea of what letters are that lettering men or type designers will never depart very far from their shapes. The

exception, of course, is the trick alphabets which are designed to startle and even shock and which therefore have a very limited, current usefulness.

Through the centuries, writing styles and even the basic letter forms were changed and modified by the materials used, and by the tendency of men to try to find ways of doing something more easily and quickly. Printing itself imposed certain changes, producing chiefly a trend toward a more mechanically perfected letter form. Since your work will usually involve either copying type or drawing letters to accompany it, you should have an understanding of type and the possibilities and limitations introduced by modern techniques of printing.

TYPE FACES

Type faces are classified according to their patterns. All authorities, of course, do not agree on the classification. Some divide type into four main groups; others into five; and still others six. For the purpose of discussion, type will be classified here under five headings: text, roman and italic, gothic or sans-serif, script or cursive, and contemporary.

The words TYPE and TYPE FACE are used interchangeably because the face of a piece of type consists of a letter cast on a metal block. (See fig. 12–2.) The size of a piece of type is usually specified in points, as 12-point type, 10-point type, 42-point, etc. There are 12 points in a pica, and six picas to an inch. The printers' rule is graduated in picas, and you should obtain such a rule if you have occasion to work with type.

If you were to measure the face on a piece of 12-point type, you might find that it falls short of 12 points, or a pica, in height. The reason for this is that the 12 points are a measure of the size of the metal block and not of the letter itself. The shoulder of the block extends beyond the letter except in a few faces, usually cursive or inclined, where the slant of the letter makes it necessary for it to overlap.

Because of the limitations of type, it is difficult for the

printer to set curved lines or to superimpose letters. When such arrangements are required, you can have him set the type and pull reproduction proofs. Then cut these proofs and paste them up in the desired arrangements. When you

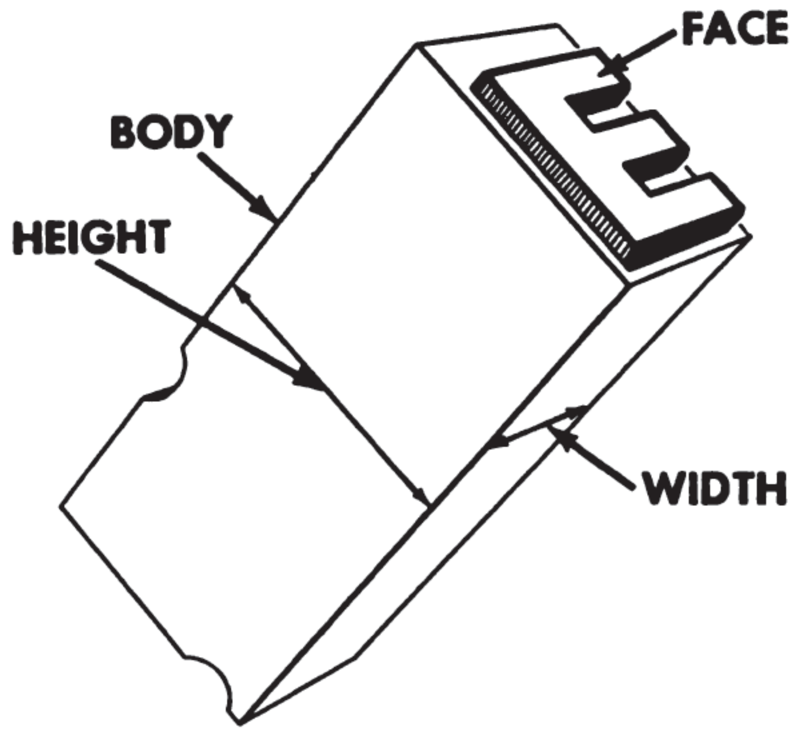


Figure 12-2.—Piece of type.

do this, leave ample margins around the letters. When they are reproduced, a photoengraving or a line negative will be made by photographic processes. The camera will also pick up the cut edge of the paste-up. This must be cut or painted out, an extremely difficult job when it is too close to the letters. A good hand-lettering man can letter the arrangement more quickly, and if necessary, modify the letters to provide a more pleasing balance. His lettering may then be reproduced directly as a line cut.

Types which are related in design are usually grouped into FAMILIES. Members of a type family often include contracted and expanded faces, as well as bold faces. Some faces, such as Futura, include three weights: light, medium, and heavy.

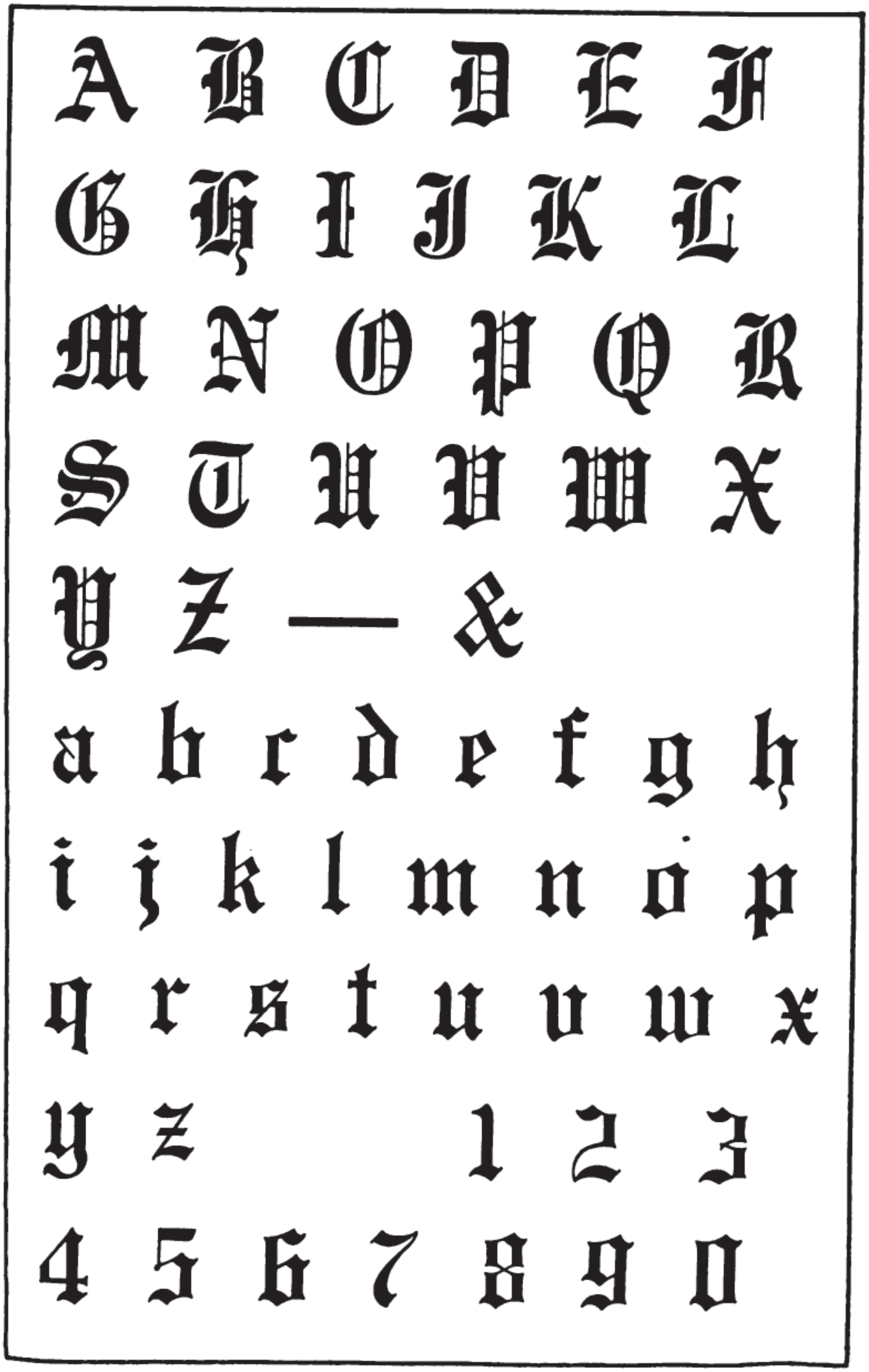


Figure 12–3.—Engravers Old English.

An alphabet of one design motif available in a full range of sizes and weights is composed of FONTS consisting of capital and lowercase letters in both vertical and italic, along with numerals and punctuation marks. Small caps are also included in the fonts of book type or type up to 14 points in size. They are about the height of lowercase letters, with which they align when printed. They are often more expanded than the capital letters and their lines are slightly heavier in relation to their size in order to combine with the capitals and lowercase letters without an alteration in weight. For this reason, they may often be used in formal layouts of title pages, etc., rather than capitals from smaller, and lighter, fonts.

Text

The first printers were also calligraphers, and they designed the first types to match what they considered the best lettering of the day. The Gutenberg Bible is printed in an angular northern black letter. A number of type faces based on the old black-letter or text alphabets are still used. Many typographers insist that this is the true gothic type and that the use of the word gothic for sans-serif faces is a misnomer.

Text is seldom, if ever, used as a book face today because when it is used for blocks of copy it is difficult to read. But it is often used for more formal and decorative purposes on certificates, formal announcements, etc. There is even a type face called Wedding Text. The example given in figure 12–3 is a type alphabet of Engravers Old English in a 48-point size. If you study this alphabet, you will see how it derives from a hand-lettered pen alphabet, with the pen held at about a 45-degree slant to the vertical, except when it is turned to make some of the thin verticals.

Roman and Italic

In Italy, the roundness of the early letter forms preceding the black letter were retained. The early Italian printers

A B C D E F
G H I J K L
M N O P Q R
S T U V W X
Y Z — &
a b c d e f g h
i j k l m n o p
q r s t u v w x
y z 1 2 3
4 5 6 7 8 9 0

Figure 12–4.—Old Style Caslon alphabets.

Figure 12–5.—Bodoni capital and lowercase alphabets.

copied these round forms in type and thus the formal Italian writing became the model for the roman lowercase letters which are commonly used for the text of our present-day books and other publications. The cursive Italian hand was developed as italic letters. Almost all roman type faces have their counterpart in italic alphabets.

Roman type faces are divided into old style and modern. The first of the old style faces were cut by men who were themselves calligraphers. But a gunsmith, William Caslon, who was accustomed to working with small steel shapes, designed the Old Style Caslon alphabets, which are still used extensively today. This type was slightly more regular and geometric than the previous letter forms. (See fig. 12–4.)

It was an Italian, Giambattista Bodoni, who took the further step away from calligraphic styles to develop a truly typographic face, distinguished by its mechanical regularity and hairline thins and serifs. His type, called Bodoni, was fashioned after letters constructed by drawing, rather than letters that were written with a pen. Its characteristics, the hairline thins and contrasting heavies, are in general the characteristics which distinguish modern roman faces from old style. (See fig. 12–5.)

Figure 12–6.—Type samples of Futura in light, medium, and heavy.

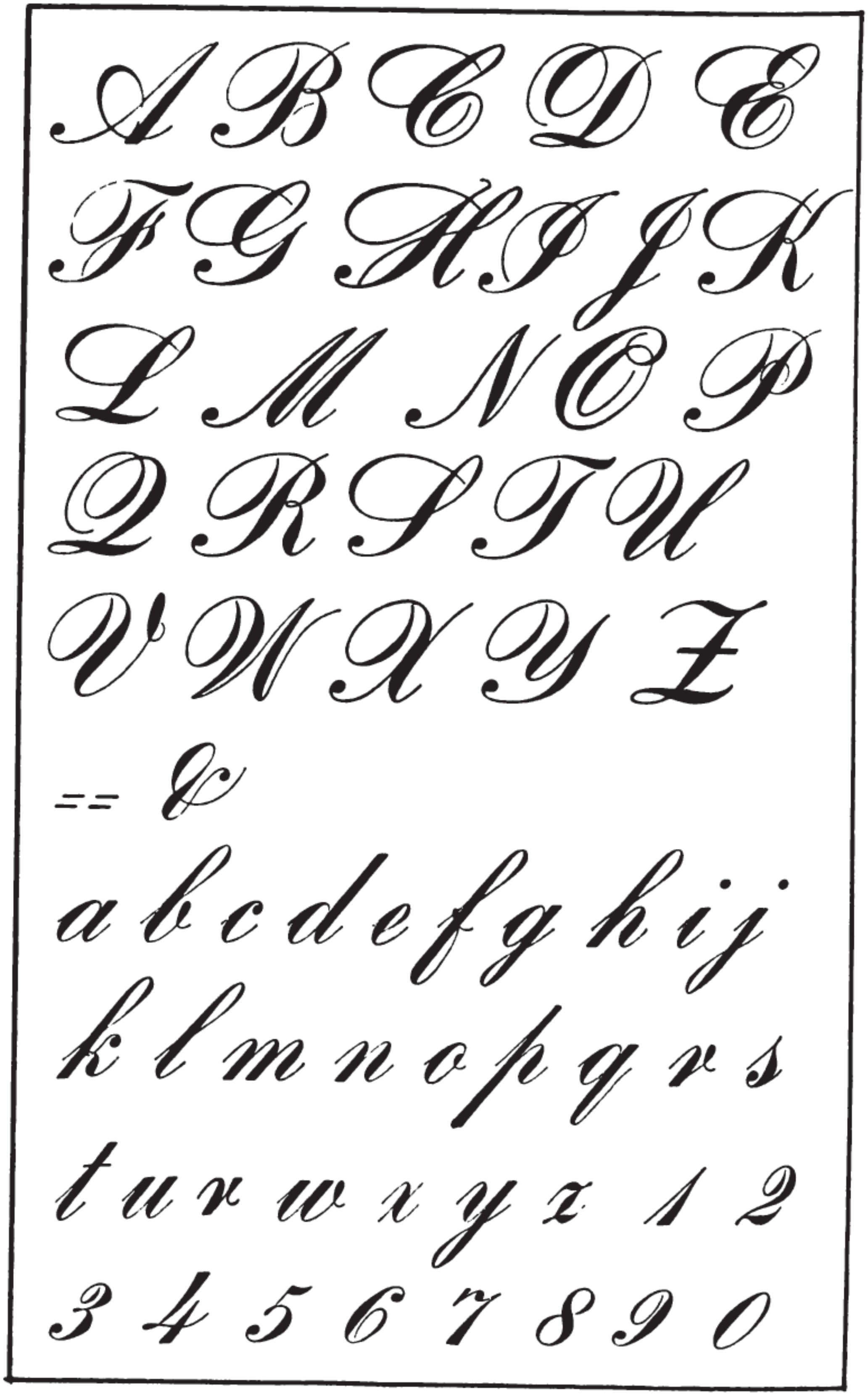


Figure 12–7.—Bank Script alphabets.

Gothic or Sans Serif

As type became less and less associated in the mind with manuscript writing, the logical development was toward a more mechanical form. Some of the gothic or sans-serif letters are almost a return to the clean letter forms of the early roman inscriptions, without the serif, which was added by cutting. Probably the most perfect of these is a modern, revised form of gothic, called Futura. (See fig. 12–6.) When these types are too heavy or when too great an effort has been made in designing them to make all the letter sizes as alike as possible, they lose considerably in legibility. And since we are accustomed to reading book type which has serifs, the sans-serif letters are less legible than roman when they are set in blocks or full pages of type. However, block or sans-serif letters are widely used on maps.

Script or Cursive

Script or cursive type faces are designed to look like written letters. Some are even connected by KERNS, called LIGATURES on written forms, and the lines widen and narrow like those made with a flexible pen, which spreads under pressure and snaps back again when the pressure is released. (See fig. 12–7.) Such types as Cartoon are designed to look like letters drawn with a lettering brush or a round-tipped lettering pen. (See fig. 12–8.)

Figure 12–8.—Sample of cartoon.

Contemporary

The so-called modern types can be said to include such faces as Futura, which we have classified as a sans-serif face. In general, these types are designed with the idea of

making something new, something purely typographic, and unlike written letter forms as they have been developed over many centuries. In a type like Ultra Bodoni, the tendency toward contrast has been carried to such an extreme that the heavy strokes have almost absorbed the COUNTER, or inside space, of the letters. Needless to say, Ultra Bodoni

EMPIRE

Ultra Bodoni

Stymie Extra Bold

Figure 12–9.—Modern type faces.

is an attention catcher, good so long as its novelty lasts, but almost illegible. Most poster or headline type suffers from a similar defect. (See fig. 12–9.)

MATERIALS

Today, as in the past, letter forms are modified by materials. As a lettering man, you may take your choice of a number of different materials, and it is your business to know which materials to use when you wish to draw a particular type of letter. However, a few simple tools which you understand and have experience with are better than a bewildering number.

Pencils

Drawn letter forms may be executed first with a pencil. In practicing drawing such letters, use an HB pencil until you can draw the letters perfectly, then use a pen to finish them, with the pencil lines to guide you.

For designing letter forms, a double pencil is useful. The two pencils may be bound together with rubber bands, and if the lettering is to be especially large, a block of wood can be inserted to increase the space between them. (See fig. 12–10.)

The double pencil is used to draw the skeleton of the letter, as illustrated in figure 12–10. The letter is then finished by the addition of serifs.

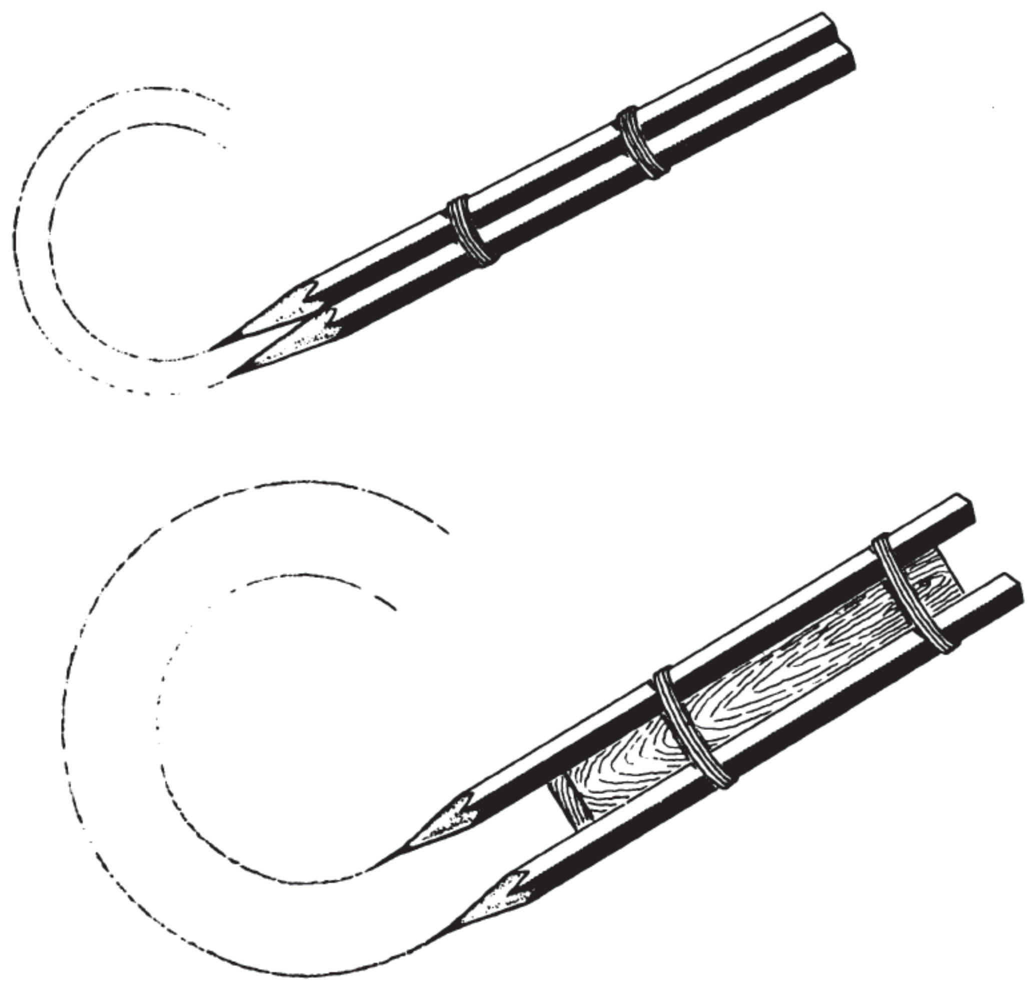
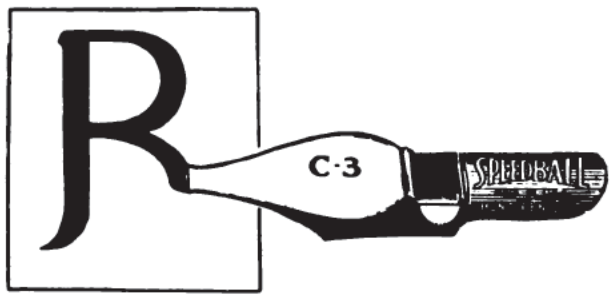


Figure 12–10.—Double pencils.

Many calligraphers insist that the best tools for fine lettering are still the quill and the reed. But the preparation of these is an art in itself. For most lettering, a short, not too flexible, steel pen with a wide nib and another similar pen with a pointed nib will serve.

Speedball penpoints are provided in varying sizes, including pens with wide nibs for making roman or text letter forms. For large sizes, a rectangular-shaped nib may be used. Speedball pens are equipped with a well for the ink. Wells may also be added to Gillott and Hunt pens. For script or cursive letters, the flexible, pointed pen called the crowquill may be used.



Courtesy Eugene Dietzgen Co.

Figure 12–11.—Speedball pen for use in lettering roman letters.

Do not dip your pen in ink. Fill it with the quill attached to the stopper of an ink bottle, a small brush, or another pen. Keep the outside of the nibs clean. Wipe the pen often on a piece of lintless cloth while you are working, and clean it carefully before you put it away. Good work cannot be done with a dirty pen.

Built-up letters are made with a small pointed pen. First, the outline is drawn and then the heavy portions are filled in with the same pen or with a brush.

You will find that the position of the pen and of the working surface are both important. The calligraphers of the Middle Ages worked with their parchment or vellum raised at an angle of about 60 degrees. At this angle, the letters

were not seen as foreshortened. You may work with the lettering surface at an angle of about 45 degrees at first, and raise the board higher as you become accustomed to the position. The old scribes held the pen nearly horizontal, which made it easier to control the ink flow. (See fig. 12–12.)

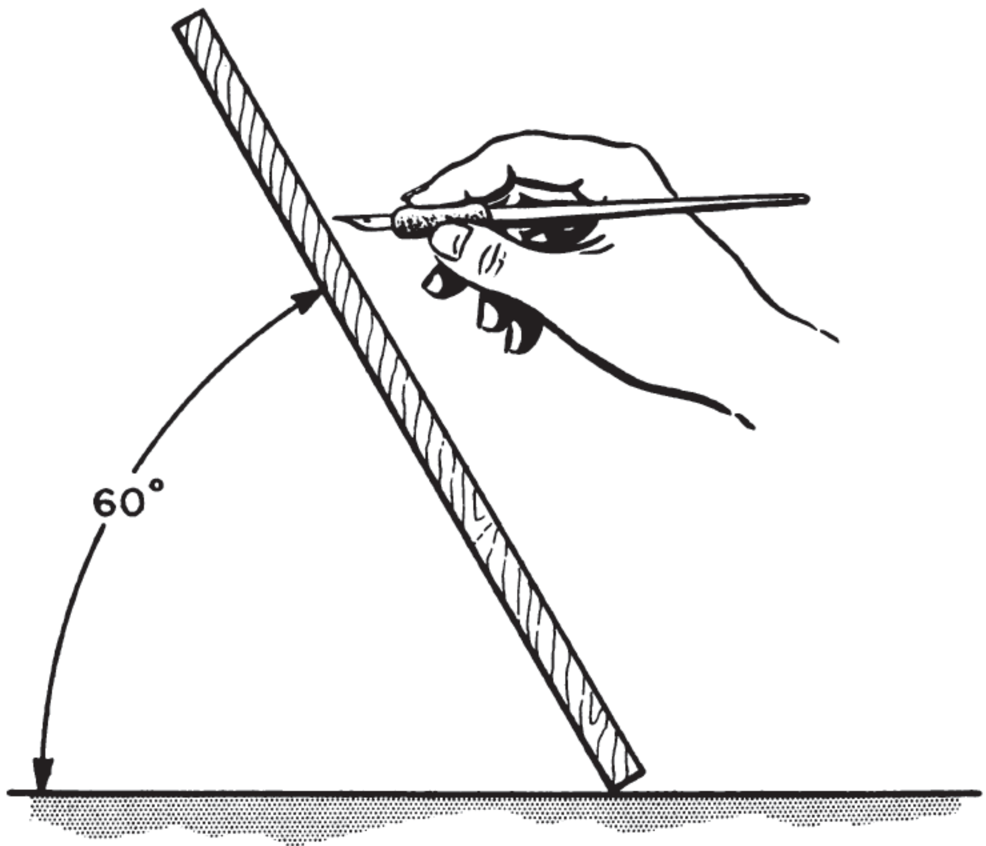


Figure 12–12.—Positions of lettering surface and elevation of the pen.

In lettering, the angle of the pen in relation to the vertical strokes of the letters is also important. Notice the difference between a letter O formed by a slanted pen and the letter O formed by a straight pen, as shown in figure 12–13. Occasionally the paper may be turned to make the angle of the pen greater. It may be turned the other way to decrease the angle, when you find it most comfortable to letter even the straight-pen forms with a slanted pen.

Hold the pen between your forefinger and thumb and rest it on your second finger, with the other fingers relaxed. Do

not grip it tightly. When the pen is held tightly, you cannot feel what the nib is doing. Rest the heel of your hand on the drawing board. Hold your left hand just under the lettering line. (See fig. 12–14.) If you hold a spatula pressed against the lettering surface, this will help not only to keep the paper firmly pressed against the pad, but also to keep your body squarely in front of your work. Some lettering men use their left hand to steady their pen hand at times. A piece of paper may be placed across the board just under the lettering line to protect the surface from hand-prints.

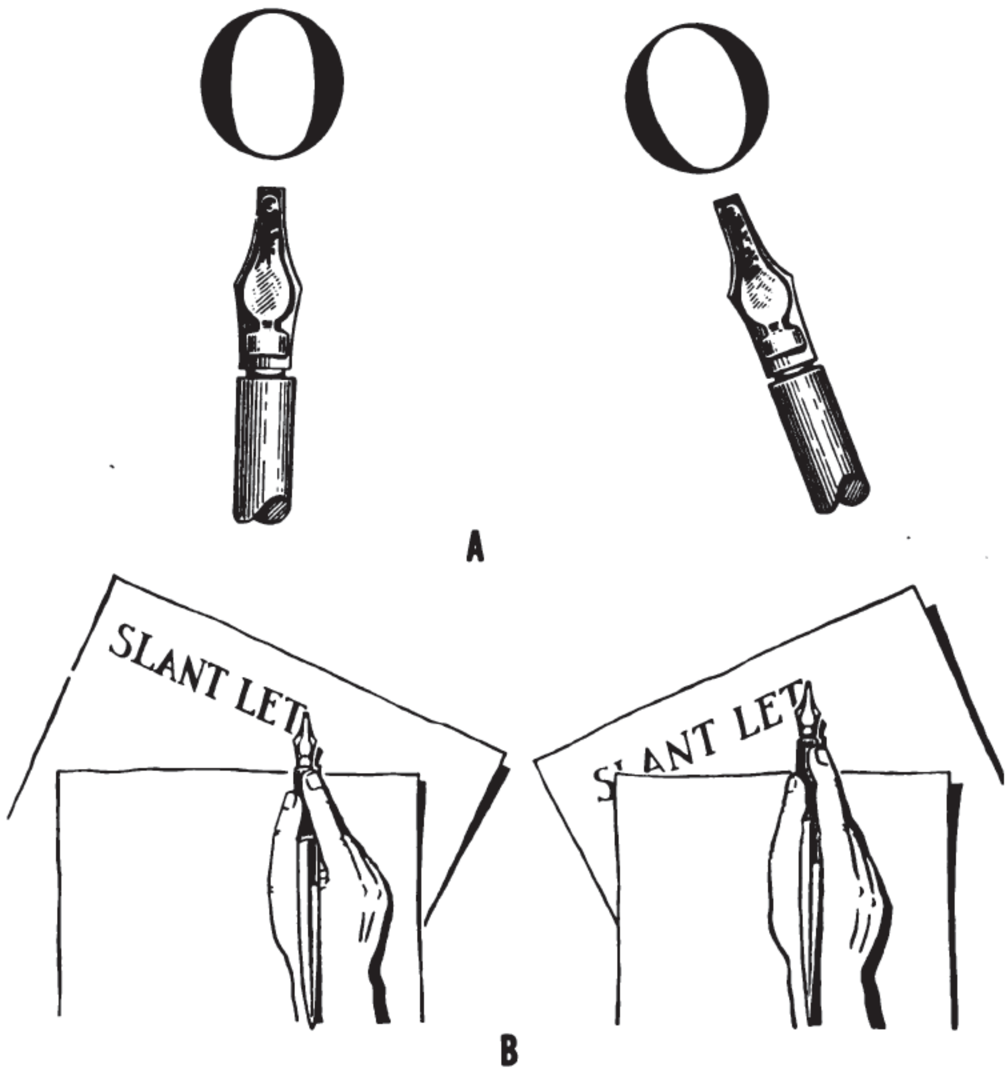


Figure 12–13.—A. Influence of the direction of the pen on letter form. B. influence of slant of paper on angle of letter.

When letters are to be drawn on a large chart or some other piece of artwork, it is sometimes necessary to work with the lettering surface in a more level position than has been recommended here. In this case, try to assume a

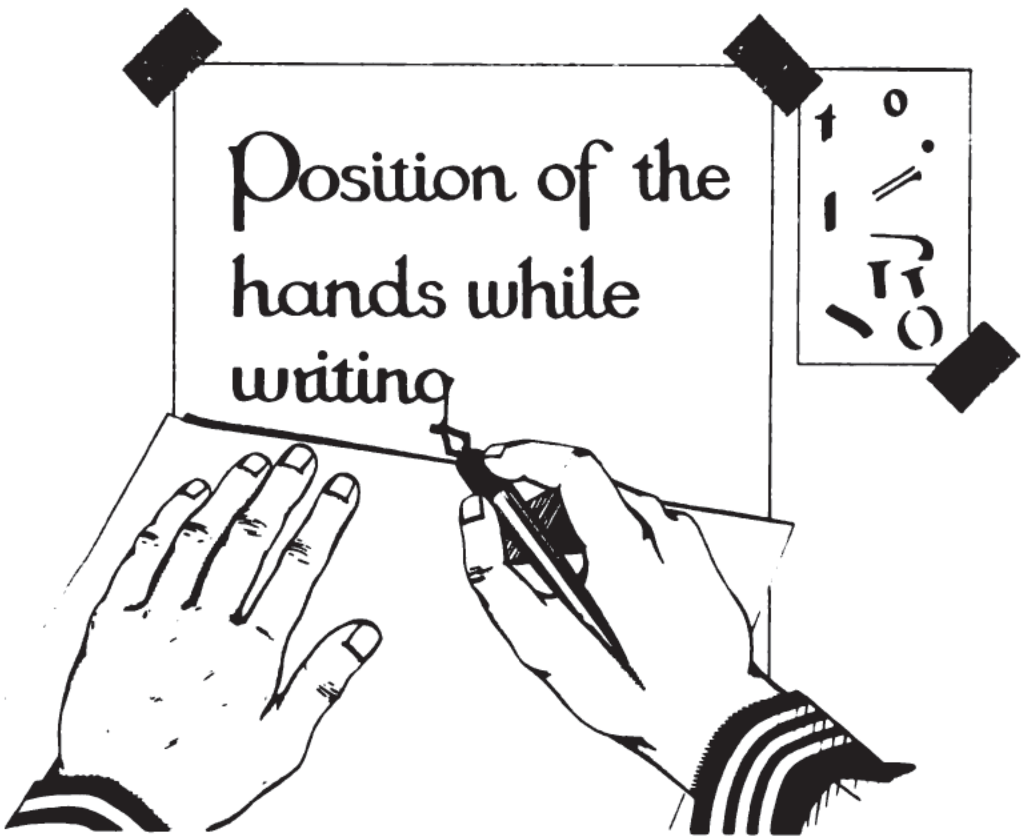


Figure 12–14.—Position of the hands.

position which will bring you sufficiently above the working surface so that you can see the letters vertically and not at a slant that makes them appear foreshortened.

Brushes

The brush is not so useful for fine lettering as the pen, because it is so flexible that it requires greater skill to produce finished letter forms. However, for less permanent lettering such as show card, the brush is a useful tool.

Some show card lettering men prefer a pointed brush, but either the round or flat lettering brushes with the bristles cut straight across at the tip are commonly used.

Paper and Ink

As a topographic draftsman, you will letter on clay-surfaced paper, plastic sheets, or other map materials. As a lithographic draftsman, you will work on zinc or aluminum plates or film negatives. As an illustrative draftsman, you will sometimes be required to draw letters on painted surfaces, using paint instead of ink, but generally you will work on paper. A smooth but not glossy surface is generally best. When lettering is to be reproduced, a white paper should be used. A hot-pressed illustration board is good for this purpose. Also, lettering which is to be reproduced may be touched up around the edges with a fine brush and opaque white water color to prevent fuzzy reproduction.

It is better to use black ink, rather than colored ink, for practice, since imperfections show up better in black ink. Colored ink tends to make letters look better than they are. Ink that is quite thick or a thick water color is hard to control and flows poorly from a pen or brush.

LETTER FORMS

Letters may be thought of in two ways: as skeletons which the tool follows and embellishes with strokes which are natural to it, or as surfaces where the boundaries are important

Figure 12–15.—Small inside spaces in a letter make it less legible.

Figure 12–16.—Sans-serif or block letter alphabets.

and which are drawn first in outline. In lettering the first type, your danger lies in a defective or debased mental image of the skeleton forms and in a failure to follow normal stroke patterns. In drawing the second type of letter, your danger lies in a tendency to build up the heavy strokes until the inside shapes of the letters become too small. (See fig. 12–15.) If the inside space becomes too small, there is a tendency for it to fill up when the letter is reproduced. The beauty, as well as the legibility, of a letter depends very much on its inside shape.

Good skeleton alphabets are shown in figure 12–16. The spaces between guide lines are given in terms of tenths of an inch for convenience in measuring with the engineers' scale. These alphabets, and the roman capital alphabet shown in figure 12–17, are taken from the Hydrographic Office publication, *Projects in Drafting for Trainees.*

Notice that the O in both the sans-serif and the roman capital alphabets is narrower than it is high. This is a clue to the relative width to height of other letters as well, since the beauty of an alphabet depends to a great extent on the uniformity of letter sizes. You will find other alphabets in which the O is as wide as it is high or slightly wider. In these alphabets, if they are well designed, other letter forms will also have widened shapes.

In studying an alphabet, this is the type of thing you should look for. For example, notice that the angle at the top of the A in figure 12–17 is quite sharp. You will find other A's in which the angle is treated differently. Also the B, E, F, R, and Y, which are generally classified as narrow letters along with the S, are as wide or wider than the L, A, N, H, U, and X. Also compare the width with the height of each letter, as well as the width of one letter with another.

The W is the widest letter in the alphabet. It consists of a double V. The two letters V and U were at one time the same letter which explains the name—double U. The V's of W are made narrower than the letter V in order to produce a W which is near the width of the other letters. Since we are accustomed to seeing the W made in this way, a W which

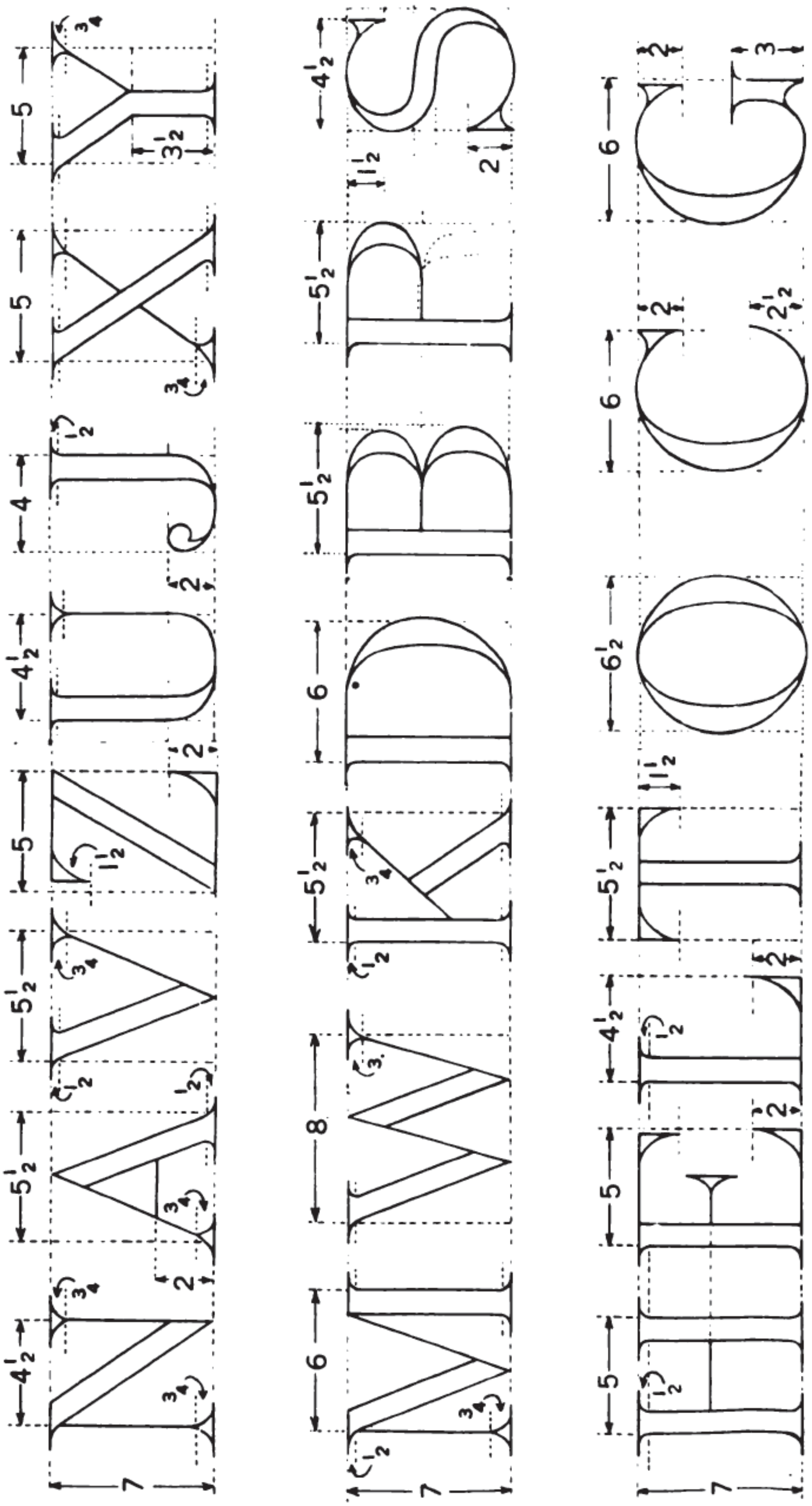


Figure 12–17.—Roman capitals.

is composed of V's as wide as the letter V jumps out from a page of letters, calling attention to its individual shape and, therefore, slowing the reader. An alphabet with such a letter, whether it is a W or some other, is not as legible as could be desired.

It has been argued that the two V's of the W should overlap or at least join at the mid-point of the inner strokes, but in this alphabet, the joint is slightly above the mid-point and the design of the letter is such that this appears to be the normal shape.

Also look at the serifs. Compare their bracketed shapes with the serifs in the alphabets shown in figures 12–8 and 12–9. See how the heavy and light lines of the letters compare with each other and with lines in other alphabets.

In B, E, F, H, P, R, S, and X, the cross bar or division is slightly above the middle of the letter. In theory, it would fall in the middle, but in order for its apparent position to be in the middle, it must fall slightly above the true center of the letter at what may be called the optical center. The optical center is above the actual center. A is an exception, and the cross bar here may fall below the optical center as it does in this alphabet.

One reason why the cross bar on the A looks well below the optical center of the letter may be that this brings the counters, or spaces, in the A to a more nearly equal area, although the lower counter is still larger. Also the A reproduces better when it is more open. The lower counter is also larger in the B, E, F, H, S, X, and Y after the cross bar is moved up in these letters. In B and S, the lower curve is also enlarged to make these letters seem more balanced or more stable—to prevent their appearing as if they might fall forward. The same thing may be seen in the slight extension of the lower arms of the R and the K beyond the upper arm and the loop.

The two outside stems of the M are vertical. Often the M is made with slanting outside stems to bring the counters below the center V to approximately the same area as the

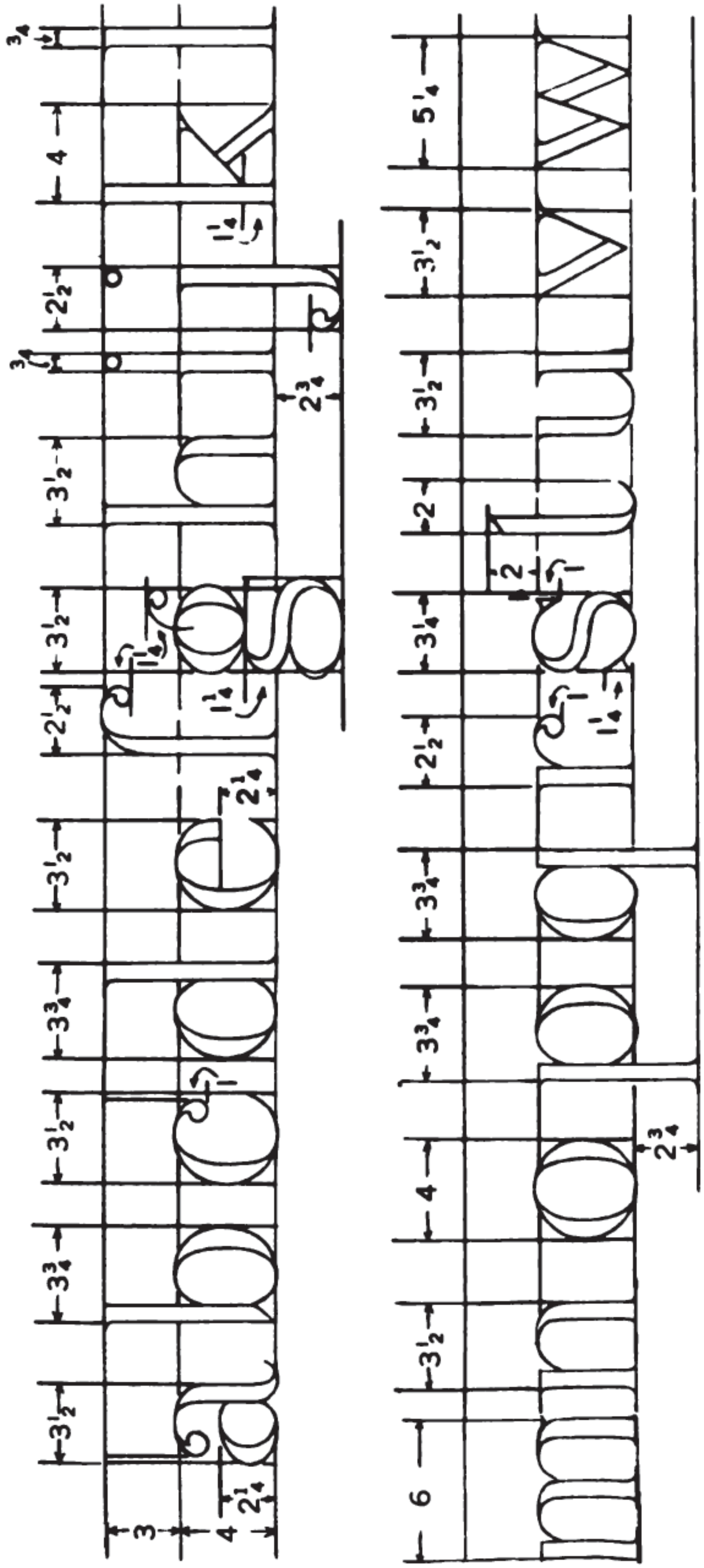


Figure 12-18.—Lowercase roman alphabet.

space, or counter, above. This is one of the concerns of a designer of letters. Not only must the space between letters be roughly equal or appear equal and the letters themselves be as close to the same width as the different letter forms allow, but also the counters within the letters should be roughly the same. These three principles of spacing tend to produce an alphabet which, by not calling attention to any singularity of space, allows the reader's eye to move smoothly over the letters. At the same time an alphabet may have its own variations which give it character. The qualities of a good alphabet are legibility, beauty, and character.

A portion of a lowercase roman alphabet is shown in figure 12–18. Study these letters, comparing their widths. Then compare them with the lowercase alphabets in figures 12–4 and 12–5, in order to see how they differ in individual characteristics from other lowercase roman letters.

As a preliminary step to the copying of any alphabet, it is of the utmost importance that virtually every letter be studied carefully. The true form of each, together with its proportions in relation to the other letters, must be clearly fixed in the mind, for not until you can visualize the letter correctly can you expect to produce a facsimile of it. Muddled perception, usually born of impatience, is probably the most common fault of a beginner. To perceive a letter correctly, constantly ask yourself these questions:

What is the width as compared to the height?

What is the true shape of the curve—is it circular, or is it slightly elliptical?

How long is this element as compared with that element?

Where is the cross bar placed—precisely at the center or slightly above?

What is the angle of this line and at what point does it join the other line?

It is when you find yourself thinking these questions automatically and subconsciously as you study and copy letters that you are really well on the way toward success in lettering. The three steps in learning to letter an alphabet con-

sist of first learning to see the letters, then impressing them on your visual memory, and finally practicing them until the muscles of your hand have also acquired a muscular memory of the letter forms.

CHART LETTERING

Lettering plays such an important role in the finish of charts and maps that the need for perfection in this element of their construction can hardly be overstressed. The lettering on a chart does much to establish the initial impression of the quality of the work. Slight imperfections that might not mar the symbols on a chart are quickly detected in the lettering. Cartography is an art, as well as a science, and lettering is part of the art.

There are several factors which enter into the production of superior lettering and topography. The aim must always be toward letters which are appropriate to the purpose. Type and lettering highly effective in advertising, book, or decorative work might be an unfortunate choice for serious charts and maps.

Letter styles on charts should be sufficiently restrained to avoid calling attention to their design. They must be legible, open enough to reproduce well by the lithographic process, yet not so bold as to kill adjacent type or to cause spottiness in the chart. They should blend in reasonable harmony when mixed.

Introducing types of widely divergent design, such as sans-serif and roman, in a single work is unavoidable when clear-cut distinctions must be made among the various elements of a chart's content. To be considered for adoption, a style usually should be available in light, medium, and bold, with italics to match, but this is not always possible. Different types which give similar effects may be used instead. Some good styles are not sufficiently economical of space to be practical for all work. Condensed or contracted forms must be resorted to and should be available.

Hydrographic Office Charts

Navy Department charts, including aeronautical charts and the charts in the *Seaplane Pilot's Handbook* or the *Seaplane Route Manual*, are produced at the Hydrographic Office. The lettering on aeronautical charts is similar to that on navigational charts, but the lettering on seaplane route charts is different in that only sans-serif types are used.

The Hydrographic Office has established certain rules concerning lettering on charts. The purpose of these is chiefly to ensure the use of different types to indicate differing features. In the past, engraved lettering was used extensively. Now, however, only the figures for soundings, abbreviations for bottom characteristics, symbols, and standard notes are engraved. The size of these are indicated by a gage number which refers to the size of the stylus used by the engraver. Foundry type or monotype is used for other lettering.

Land features are shown in vertical lettering, and water features are shown in leaning lettering. Important features are shown in caps. Any feature larger than 12-point type is shown in caps. Place names are generally shown in full strength, that is, roman type. Descriptive notes and secondary names are set in sans-serif type. The following table gives the names of type faces used.

Type Standards for Navigational Charts

LAND NAMES

18 Pt. Lining Title
14 Pt. Lining Title
12 Pt. Lining Title
12 Pt. Roman Caps
12 Pt. Bodoni Book Caps
12 Pt. Bodoni Book Lower Case
10 Pt. Bodoni Book Caps
10 Pt. Bodoni Book Lower Case
8 Pt. Century Expanded Caps
8 Pt. Century Expanded Lower Case
8 Pt. Bodoni Book Caps
8 Pt. Bodoni Book Lower Case
6 Pt. Century Expanded Caps
6 Pt. Century Expanded Lower Case
6 Pt. Bodoni Book Caps
6 Pt. Bodoni Book Lower Case
14 Pt. Lightline Caps
12 Pt. Lightline Caps
10 Pt. Lightline Caps

WATER NAMES

14 Pt. Century Expanded Italic Caps
12 Pt. Century Expanded Italic Caps
12 Pt. Bodoni Book Italic Caps
12 Pt. Bodoni Book Italic Lower Case
10 Pt. Bodoni Book Italic Caps
10 Pt. Bodoni Book Italic Lower Case
8 Pt. Century Expanded Italic Caps
8 Pt. Century Expanded Italic Lower Case
8 Pt. Bodoni Book Italic Caps
8 Pt. Bodoni Book Italic Lower Case
8 Pt. Bernhardt Gothic Italic Caps
8 Pt. Bernhardt Gothic Italic Lower Case
6 Pt. Bernhardt Gothic Italic Caps
6 Pt. Bernhardt Gothic Italic Lower Case
6 Pt. Lining Gothic Italic Caps No. 524
5 on 6 Pt. Lining Gothic Italic
6 Pt. Century Expanded Italic Caps
6 Pt. Century Expanded Italic Lower Case

For names of STRAIT, CHANNEL, CANAL, PASSAGE, and PASS to be larger than 8 Pt. Bernhardt Gothic Italic Caps, use 10 or 12 Pt. Bodoni Book Italic Caps, then 12, 14, 18, or 24 Pt. Century Expanded Italic Caps.

ELEVATIONS

6 Pt. Century Expanded
5 Pt. Century Expanded
6 Pt. Lightline No. 3 (for contour lines)

VARIATION CURVES

6 Pt. Light Copperplate Gothic No. 34, Caps

PROJECTION AND SCALE FIGURES

Nautical Miles	6 Pt. Lt. L. No. 4 Lower Case
Figures	6 Pt. Lt. L. No. 3
Yards	6 Pt. Lt. L. No. 4 Lower Case
Figures	6 Pt. Lt. L. No. 3
Meters	6 Pt. Lt. L. No. 4 Lower Case
Figures	6 Pt. Lt. L. No. 3

Scale Borders

	No. 40 to No. 50	*No. 55 to No. 65*
Degrees	8 Pt. Bodoni Book	10 Pt. Bodoni Book
Minutes	6 Pt. Bodoni Book	8 Pt. Bodoni Book

Plan Borders

	No. 30 to No. 35	*No. 40 to No. 50*	*No. 55 to No. 65*
Degrees	6 Pt. Lt. L. No. 4	8 Pt. Lt. L.	10 Pt. Lt. L.
Minutes	6 Pt. Lt. L. No. 3	6 Pt. Lt. L. No. 4	8 Pt. Lt. L.
Seconds	6 Pt. Lt. L. No. 2	6 Pt. Lt. L. No. 3	6 Pt. Lt. L. No. 4

NAVIGATIONAL AND RADIO AIDS

Fixed—

6 Pt. Lightline No. 4 Caps and Lower Case

Floating—

6 Pt. Bernhardt Gothic Italic Caps and Lower Case, Numbers and letters of buoys.

DESCRIPTIVE NOTES AND SECONDARY NAMES:

Land—

10 Pt. Lightline Caps and Lower Case.

8 Pt. Lightline Caps and Lower Case.

6 Pt. Lightline No. 4 Caps and Lower Case.

6 Pt. Lightline No. 4 Caps and Lower Case (Also 8 Pt. and 6 Pt. No. 3). Begin with Cap, when particular point or object is indicated.

6 Pt. Lightline No. 3 Caps.

6 Pt. Lightline No. 2 Caps.

Water—

10 Pt. Draftsman Italic Caps.

8 Pt. Draftsman Italic Caps and Lower Case.

6 Pt. Draftsman Italic Caps and Lower Case.

6 and 8 Pt. Draftsman Italic Caps and Lower Case.

Begin with Cap when indicating a danger or when of importance to the navigator.

Type Stick-Up

Type proofs are first pulled on special proving presses. These proofs are backed with adhesives or wax and positioned on the original chart by the draftsman. The type may be printed on white paper backed with a thin layer of adhesive or on both sides of transparent plastic simultaneously and in perfect register. The plastic is then coated with wax or with wax to which white pigment has been added.

The draftsman has only to cut out with a sharp knife the letters to be placed together on a map. He should take care to leave enough space around the letters so that the shadow left by the edge can be painted out on any negative. The

cut-out piece is then positioned on the surface of the map. A burnisher is used on the wax-coated plastic.

Letter Spacing

Letter spacing is the term applied to the opening up or stretching of words, an essential practice in chart and map construction. Since more space must be evaluated in each unit of letter spacing, it is somewhat more difficult for the lettering man than normal spacing. However, the same rule applies. Letter spacing merely requires a more expertly trained eye. Simply add the correct minimum spacing according to the needs indicated by the shapes of the letters, plus the unit of uniform increase that is to be added between all letters in a word or line. (See fig. 12–19.) Even mediocre lettering can be made to look professional if it is spaced properly.

ATLANTIC OCEAN

A T L A N T I C   O C E A N

Figure 12–19.—An example of letter spacing.

In meeting predetermined measures or line lengths, you should prepare a carefully spaced draft on tracing tissue before working on the lettering surface. This procedure also helps when you are lettering lines based on a curve, especially when the precise curve has not been established. Diagonal guidelines may be used on the tracing paper to retain a consistent slant in leaning letters. Transfer the perfected draft with the tracing point and a blue-paper underlay, using tape to hold the tissue draft in position.

ILLUSTRATIVE LETTERING

The illustrative draftsman usually has a far freer choice of lettering styles, but for this very reason, he is far more likely to produce tasteless lettering. When hand lettering is to be reproduced with type, it does not have to match the letter

forms of the type faces used, but it should be designed to go well with them. When lettering is to accompany an illustration, it should match the style of the illustration. You would not use the same kind of lettering for both a female fashion advertisement and a battle poster.

This does not mean that you must struggle to design new letter forms for each job. The basic skeleton alphabet may be the same. But much can be done to make your letters suitable in different contexts by altering weight of strokes and using different tools, writing the letters with a pen for one job and drawing them for another.

One of the most important things to watch in letters to be reproduced in publications is the weight or color of the lettering in comparison with that of the text or blocks of type. Contrast is good, but hand lettering that is lighter in weight than adjoining type-set matter must be very distinctive in character or it may merely look weak by comparison. On the other hand, rough, heavy, hand lettering combined with a distinctive and delicate type will look as if it were not professionally done.

Remember that hand lettering which is reduced considerably in reproduction may alter its character completely, especially its weight or color. One-third reduction is the safest, although one-half may be used. If in doubt concerning what reduction will do to your lettering, look at it through a reducing glass. Type faces are not designed to be reduced. A 36-pt. letter in a certain face will not look like the same letter in a 10-pt. alphabet of the same type if it is reduced to the same size.

Hand lettering which is to be used on a poster or placard must be large enough to be read by someone standing at a distance. If you are asked to letter a sign for some particular purpose and place, you can make a test with several samples to determine which looks best and how large the lettering should be. When a poster is to be printed and distributed, the problem is not so easy to solve. But remember

that it is important that your letters be read, and draw them large enough and clear enough so that they will be easily read.

For a discussion of layout and publication typography, read chapter 15 in this manual.

QUIZ

1. How is the size of a piece of type specified?
2. How many points are there in a pica and how many picas to an inch?
3. What does the point size of a type face refer to?
4. Why is text seldom used as a book face today?
5. How does the so-called modern roman type face Bodoni differ from old style roman type faces?
6. Why are the sans-serif faces usually considered less appropriate for books than the roman type faces?
7. Why is it a good idea to work with the lettering surface at an angle of about 60 degrees?
8. Why should you not hold a lettering pen tightly?
9. Why should the inside spaces, or counters, of letters to be reproduced be fairly open?
10. Why is the cross bar or division in many letters slightly above the middle of the letter?
11. What three principles of spacing should be incorporated in an alphabet in order to eliminate any singularity in spacing?
12. What are the three steps in learning to letter an alphabet?
13. Why are a number of different type faces used at the Hydrographic Office?
14. How is type applied to an original chart?
15. What does the term LETTER SPACING mean?
16. What may happen to hand lettering which is reduced considerably in reproduction?

CHAPTER 13

MAPS AND CHARTS

PLANNING COMES FIRST

Whether you are assigned to a survey ship, an aircraft carrier, a construction battalion, or some other activity, you will be dealing with maps and charts constructed according to specifications set up by Government agencies such as the Hydrographic Office, the Bureau of Yards and Docks, or the Coast and Geodetic Survey. Wherever you work, the work that you do will be affected by the materials and equipment available.

If you do the artwork for a chart which must be very accurately scaled on a drawing material which is subject to gross changes under varying atmospheric conditions, your work will be worse than useless. If you prepare artwork which is too large to be reproduced on the press plates available, you have committed an inexcusable error. It is your business not only to know how to draw a chart, but also how it will be reproduced and even how it will be used.

Such considerations as these affect the planning of the chart before even a pencil is put to the surface of the paper, plastic, or zinc sheet. Although as a Draftsman 2, you will not be expected to plan charts, it will pay you to be able to detect the more obvious errors in planning, if merely in terms of saving yourself wasted time and effort. Also this is the time when you learn the basic things to be considered, so that later, when it is your job to plan, you will not be guilty of gross errors.

CONSTRUCTION OF A MAP

A map is a conventional representation of a part of the earth's surface projected onto a plane. Charts are maps which originally were designed to show bodies of water, with islands and coast lines, for navigational and piloting purposes. More recently the time honored distinction between maps and charts has nearly vanished with the evolution of a graphic mongrel called chart-map which depicts both landward topography and off-shore hydrographic data in great detail. It has been incorrectly stated that all maps lie. Maps can mislead those who do not understand the inherent problems of each map projection and its construction.

A spheroid, like the earth, is a nondevelopable geometric form. That is, it cannot be flattened into a plane without both stretching and shrinking, which produces distortion. The problem of map projection consists of finding some method of transferring the network of meridians and parallels from the globe to the mapping plane, and then fitting the geographical features to this network. The work of making maps, therefore, consists of two separate processes:

1. Making correct maps of smaller areas by surveying or photogrammetry.
2. Fitting together these small maps to a system of lines representing meridians and parallels. The system of lines is a map projection.

Geographic Coordinates

To define accurately positions on the earth's surface, it is necessary to accept fixed reference planes and surfaces. The surface of mean sea level has been generally adopted as the surface of zero altitude. The meridian passing through Greenwich, England, near London, is usually taken as the prime reference meridian from which longitude is measured halfway around the globe, positive to the west and negative to the east. The Equator is taken as the reference parallel from which latitude is measured to the poles, positive to the north and negative to the south. While the algebraic

signs of the latitude and the longitude show whether they are north or south, east or west, the letters N, S, E, and W are usually used, being placed after the figures.

The United States and most foreign countries use the Greenwich meridian as the meridian of zero longitude. Some foreign maps, however, are based on some other meridian as a prime meridian. Some have used the Ferro Islands and several the capital of their respective countries—Paris, France, for example—as the location of the zero meridian.

Parallels of latitude and meridians of longitude are measured by two systems:

1. The sexagesimal system, using degrees, minutes, and seconds. This is the predominant system and is used in the United States, Britain, Netherlands, China, Scandinavia, Germany, Italy, and Japan.
2. The centesimal system, using grads and decimal fractions of grads. This system is used in France and by countries who were influenced by the French.

The basic relation between grads and degrees is 100 grads equal 90 degrees.

Measurements of the Earth

Actually, the earth is not a perfect sphere. Because of the earth's rotation and the force of gravity, it is a slightly irregular ellipsoid. There are several ellipsoids, but the one generally used by the Navy is Clarke's spheroid of 1866. The following dimensions of the earth are values used by the Coast and Geodetic Survey in its computations. They were taken from Special Publication No. 138.

Equatorial radius	6,378,206.4 meters
Polar semiaxis	6,356,583.8 meters
One kilometer	0.621370 statute mile
One meter	0.000621370 statute mile 39.37 inches 3.2808333 feet
One statute mile	1,609.35 meters 1.60935 kilometers 5,280 feet
One foot	0.30480061 meter

As of 1 July 1954, the international nautical mile was adopted for use by the Defense Department. A nautical mile was originally considered to be a minute of latitude, but as the elliptical dimensions of the earth were measured more exactly, it was discovered that a minute of latitude varied so that a nautical mile at the Equator was smaller than a nautical mile at the poles. The variation is from 1,842.9 meters at the Equator to 1,861.7 meters at the pole. Consequently, a nautical mile came to be considered as equal to a minute of latitude, or 1,853.25 meters, at latitude 48°15′. These figures are changed slightly by the new directive. Thus,

$$\text{One international nautical mile} \text{------} \begin{cases} 1{,}852 \text{ meters} \\ 1.852 \text{ kilometers} \\ 6{,}076.10333 \text{ feet} \end{cases}$$

Characteristics of Map Projections

A map projection does not eliminate distortions, which are present in all large area maps; it merely controls such distortions or limits them to certain portions of the area mapped. Map projections are usually constructed from mathematical computations, but certain projections have a geometric origin. These geometric projections are constructed by projecting, using carefully controlled methods, the meridians and parallels of the spherical earth upon one of the following forms: cylinder, cone, or plane. The cylinder and cone, unlike the sphere, can be developed into a plane.

The ideal projection would produce a map which depicts (1) true shapes (conformal, orthomorphic), (2) true areas (equal area, homolographic), (3) true distances, and (4) true directions. Since there is no ideal projection, and hence no perfect map which meets all four requirements, it is essential for anyone trying to make map measurements with any degree of accuracy to know the limitations and advantages of each type of projection in order not to be misled by the various kinds of distortion.

Types of Map Projections

Of the many map projections, only four have wide use in the Navy. They are:

1. Mercator, found chiefly on hydrographic and air navigation charts.

2. Gnomonic, found chiefly on H. O. Great Circle Sailing Charts and Tracking Charts used for radio bearing interception operations (directive finding) and air-sea rescue operations.

3. Lambert conformal conic (with two standard parallels), found on certain series of aeronautical charts. Also used to some extent for meteorological plotting charts by the aerological unit of the Navy.

4. Polyconic, found on field survey sheets, and naval bombardment and air support charts.

MERCATOR PROJECTION

For navigational purposes, the Navy uses the Mercator more than any other projection. On the Mercator, meridians of longitude and parallels of latitude are straight lines intersecting at right angles. The distances between meridians are equal throughout the chart, but distances between parallels increase progressively from the Equator toward the poles. Since on the globe, the meridians approach each other until they meet at the poles, the fact that the distances between meridians on the Mercator projection are kept the same means that the distances between parallels must be increased in order to keep the scale in proportion to the scale on the earth. Although the scale values vary from point to point, the scale at any point on the chart is the same in all directions. Thus a chart constructed on a Mercator projection has what is called CONFORMALITY. Any map or chart upon which the meridians intersect the parallels at right angles has the property of conformality, or true shape.

The Mercator projection has a number of advantages, among which are:

1. Conformality.
2. Simplicity of construction.
3. Convenience in plotting positions from the border divisions.
4. The fact that a ship's course can be laid off from any meridian or compass rose within its borders.

Its principal advantage, however, and the one responsible for its world-wide use for nautical charts, is that any straight line drawn on it in any direction is a RHUMB LINE or LOXODROMIC CURVE.

The shortest line between two points on the earth is always a great circle line, but any great circle line which is not on a meridian or the Equator constantly changes direction in respect to the poles and crosses successive meridians at different angles. On the other hand, a rhumb line, while it is not the shortest line between two points on the earth, is better for purposes of navigation, because it keeps a constant compass direction, passing each meridian at the same angle. Thus, the track of a ship on a constant course, which is a rhumb line, is a straight line on the Mercator projection and it will pass all features along that line exactly as they are charted.

The greatest disadvantages of the Mercator projection are that it makes a comparison of areas very misleading when large differences of latitude are involved and that great circle routes cannot be plotted conveniently on it without the use of an auxiliary gnomonic chart. (See fig. 13–1.) Other disadvantages are that the scale is constantly changing with the latitude, with the result that a graphic scale cannot be used on smaller scale charts. This makes it necessary to measure distances along the border divisions for the latitudes in which the distance lies, and also for great distances, to adjust bearings before plotting. Also on a Mercator projection, a great circle line appears to be longer than a rhumb line, as shown in figure 13–1.

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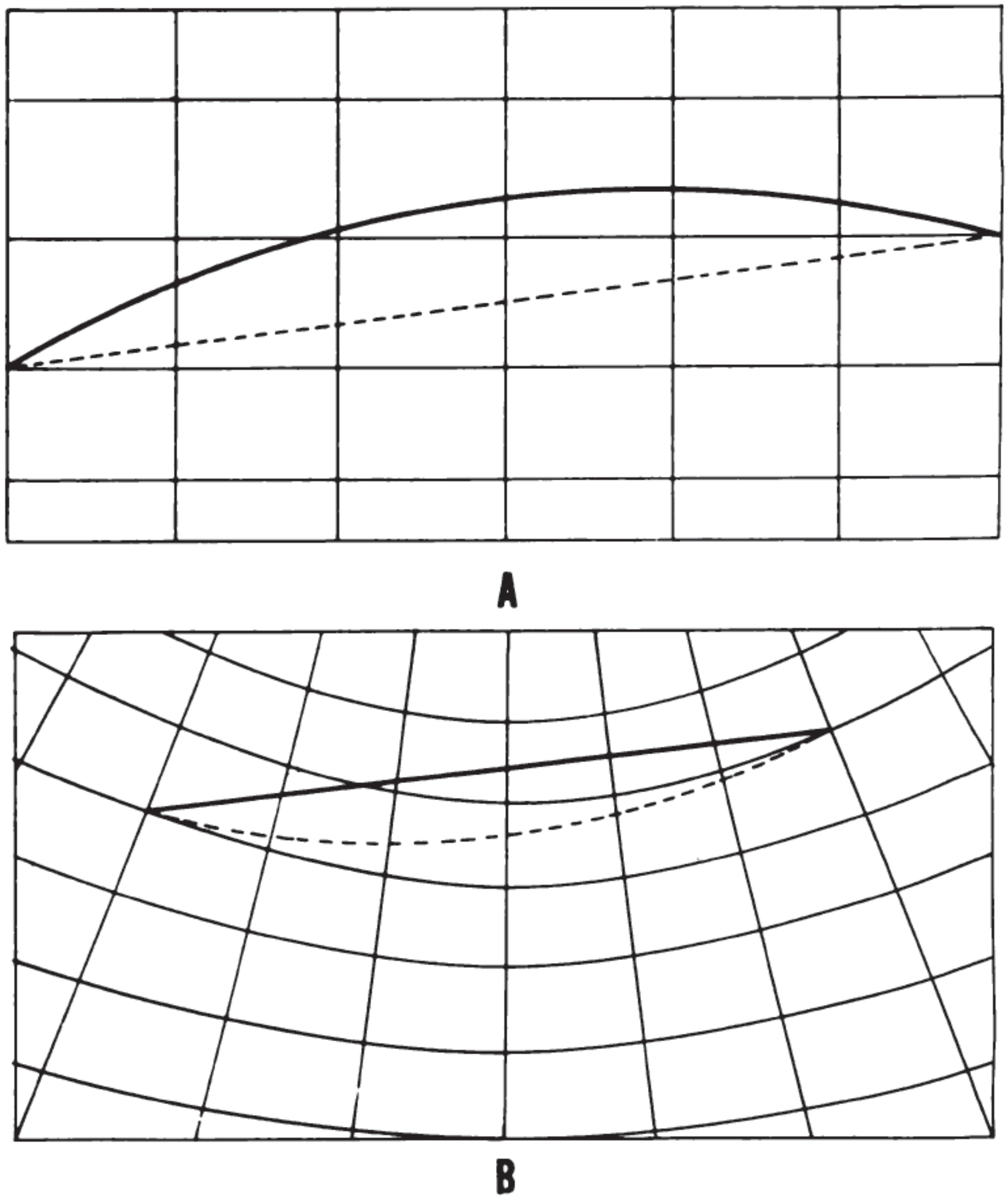


Figure 13–1.—A. Part of a Mercator chart showing a rhumb line (dotted) and a great circle. B. Part of a gnomonic chart showing a great circle and a rhumb line (dotted).

Mathematics of the Mercator Projection

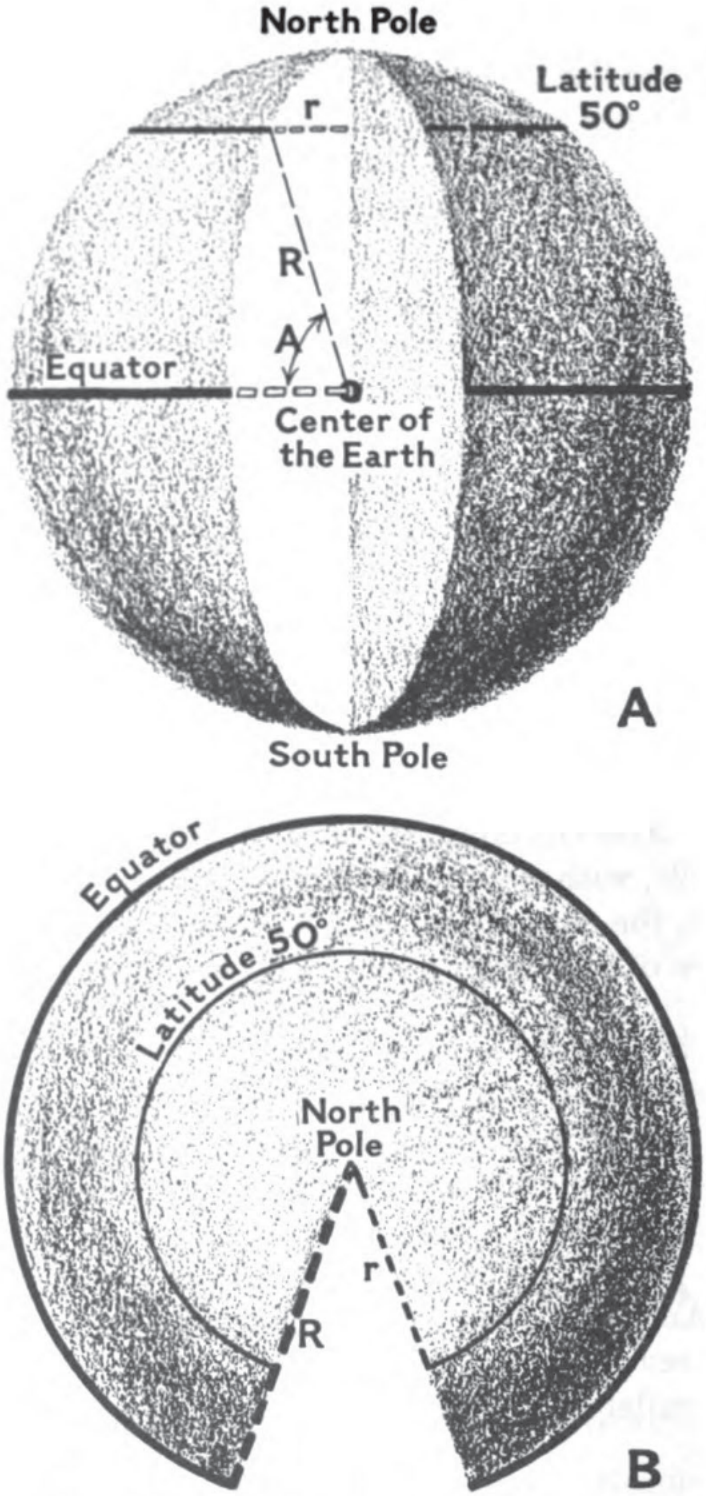
The Mercator projection is sometimes classified as a cylindrical projection. Actually, it cannot be developed geometrically. Its sixteenth century originator, Gerhard Kramer, whose Latin surname was Mercator, thought of it purely in terms of the mathematics involved.

On the earth, as you know, the distance between two meridians becomes smaller as the meridians approach the poles. A degree of latitude and a degree of longitude are approximately equal at the Equator but, as we move away from the Equator north or south, a degree of longitude becomes shorter while a degree of latitude remains the same. In the Mercator projection, the distance between meridians is kept constant; therefore, the value for a degree of longitude, instead of that for a degree of latitude, is kept the same. Now, in order that the distances represented on the map remain proportionately the same, the value for a degree of latitude is increased in proportion to the distance from the Equator.

The relationship between the values of the degrees of longitude at different parallels can be expressed in a single proportion, as shown in figure 13–2. In the figure, a sphere representing the earth has a section cut out between two meridians. The circumference of the earth at the Equator can be expressed as $2R$, with R representing the radius of the great circle. Also the circumference of latitude 50° can be expressed as $2r$, with r representing the radius of the small circle. Then, the circumference of the small circle is to the circumference of the large circle as $\frac{2r}{2R}$ or as $\frac{r}{R}$. Note that this fraction is the cosine of the angle at latitude 50 degrees.

Since this relationship is true for the circumferences of the circles, it is true for any portion of them, and therefore true for the relationship between degrees of longitude. Since meridians are, like the Equator, great circles of the earth, the fraction also expresses the relationship between degrees of longitude. And similarly, the fraction expresses the relationship between the value of a degree of longitude measured along any parallel and a degree of latitude measured along any meridian.

As you can see, the R of the fraction remains constant, the fixed radius of the earth, but the r varies progressively as the parallels approach the poles. On the Mercator projection, the lines of the parallels are all the same length, all equal to the line of the circumference of the Equator; thus,



From The Round Earth on Flat Paper, *by William Chamberlin.*
Courtesy of the National Geographic Society

Figure 13–2.—The fraction $\frac{r}{R}$ gives the value of units of longitude.

the r on this projection has a constant value. Therefore, in order to maintain the relationship between r and R which is found on the sphere, the R values must increase progressively as the parallels approach the poles. This is achieved by increasing the space between parallels by $\frac{1}{\cos}$, or the secant, of the latitude. In the Mercator projection, the scale along the parallels is sec θ of the respective parallels, and since the scale is constant at a point, the scale along the meridian at the point is also equal to the secant of the latitude of the point.

GNOMONIC PROJECTION

In this projection, the eye of the observer is conceived to be situated at the center of the terrestrial sphere, from which, being in the plane of every great circle, it will see these circles projected as straight lines upon a plane tangent at a central point. Necessarily then, a straight line between any two points on a gnomonic chart represents the great circle track line or shortest route on the earth's surface between them. (See fig. 13–3.)

When the plane of projection is tangent to a pole, the chart looks like a polar projection, showing meridians as straight radiating lines and parallels as concentric circles whose radii are equal to the cotangent of the latitude multiplied by the radius of the projecting sphere. When the plane is tangent to the Equator, the meridians are parallel straight lines and the parallels are hyperbolic curves. When the point of tangency is at any other random latitude the parallels appear as parabolic curves, eventually becoming ellipses in the higher altitudes.

The gnomonic projection has been used chiefly as an adjunct to the Mercator system to which the route finally selected can be transferred by selecting several points from the gnomonic track, replotting them on the Mercator chart, and connecting them with straight line segments. The great circle thus transferred becomes a curved line on the Mercator

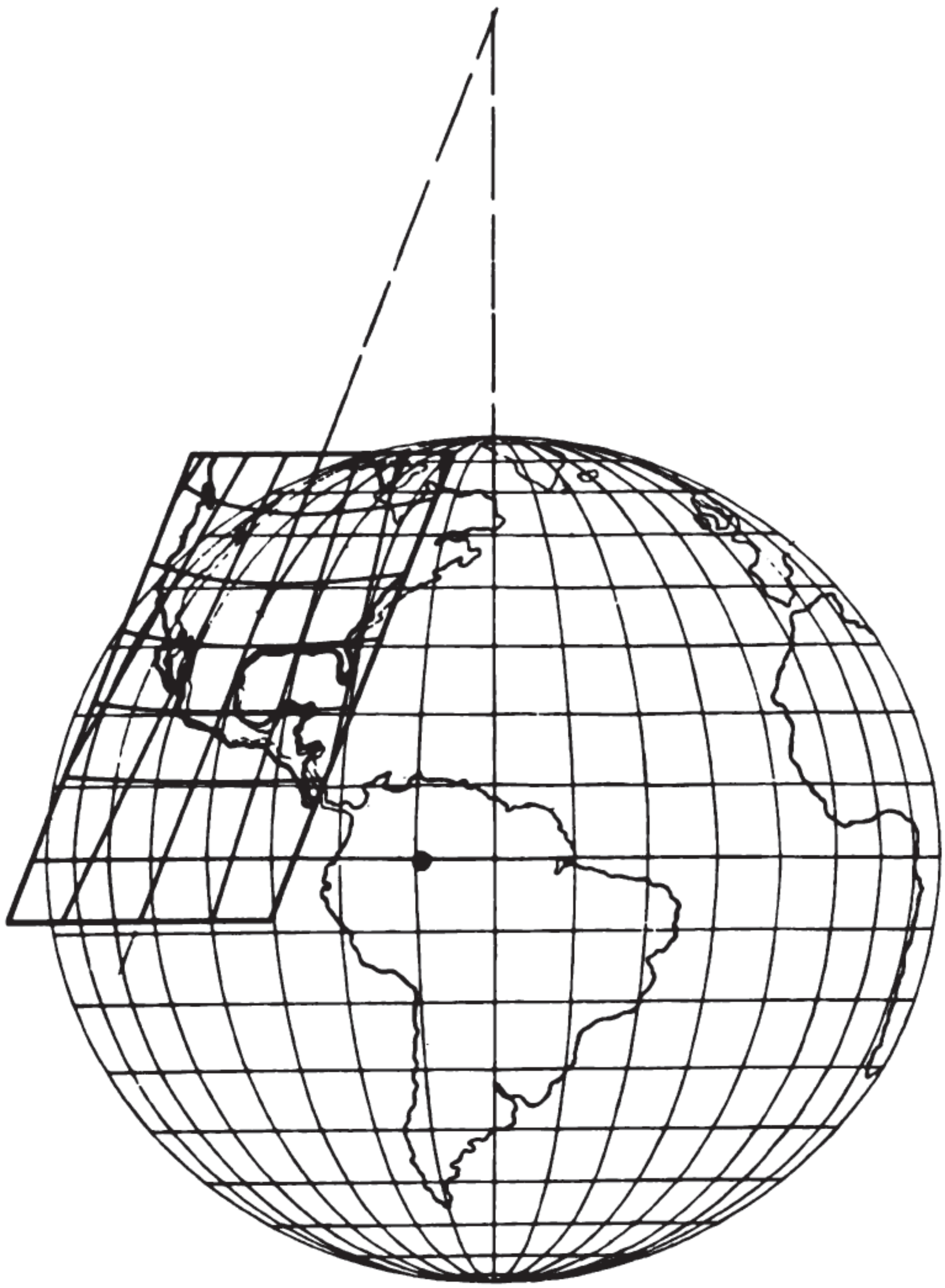


Figure 13–3.—Gnomonic projection.

projection, where it may be resolved into more convenient sailing chords. Further, the gnomonic is used extensively for D/F plotting, for radio interception operations and for air-sea rescue work.

A gnomonic chart is especially useful in the study of air routes and in the ready solution of problems involving the definite location of the minimum line between two points on the earth's surface. It is extremely useful as an adjunct to the Mercator system and serves as a general control and office reference map. Equipped with special compass roses and a border coordinate system of tabulating D/F radio bearings, this type of chart is extremely useful for plotting intercepted signals from submarines and aircraft. Course diagrams on the chart make it easy to scale distances by difference of latitude and difference of longitude methods. Also a device is available for use with the gnomonic for determination of course and distance by inspection.

However, the gnomonic projection also has disadvantages. Localities near the map boundary become greatly distorted in distances, areas, and shapes. The area which can be mapped is less than a hemisphere because at 90° from the center of the plane of projection, projectors are parallel to the plane of projection.

LAMBERT CONFORMAL CONIC PROJECTION

The Lambert conformal conic projection is used for charts at the higher latitudes. For example, charts of the Canadian archipelago are gradually being converted to the Lambert. It represents one of the earliest applications of higher mathematics to map projections. It is truly a mathematical projection although it is often represented geometrically by a cone which intersects the sphere along two standard parallels which should be not more than 20° apart in order to maintain a certain accuracy and limit scale error to a minimum. (See fig. 13–4.)

By the same standard, the total area mapped should not include more than 30° of latitude. The Lambert conformal

conic is calculated not only to hold the ratio of equal arc of any two chosen parallels but also the exact lengths of both of them. Within the two standard parallels the scale is compressed (made smaller) and outside the standard parallel it is expanded. The oblateness of the earth is taken into consideration in the tables for calculation. From practical considerations this is not always necessary, and the construction becomes fast and simple.

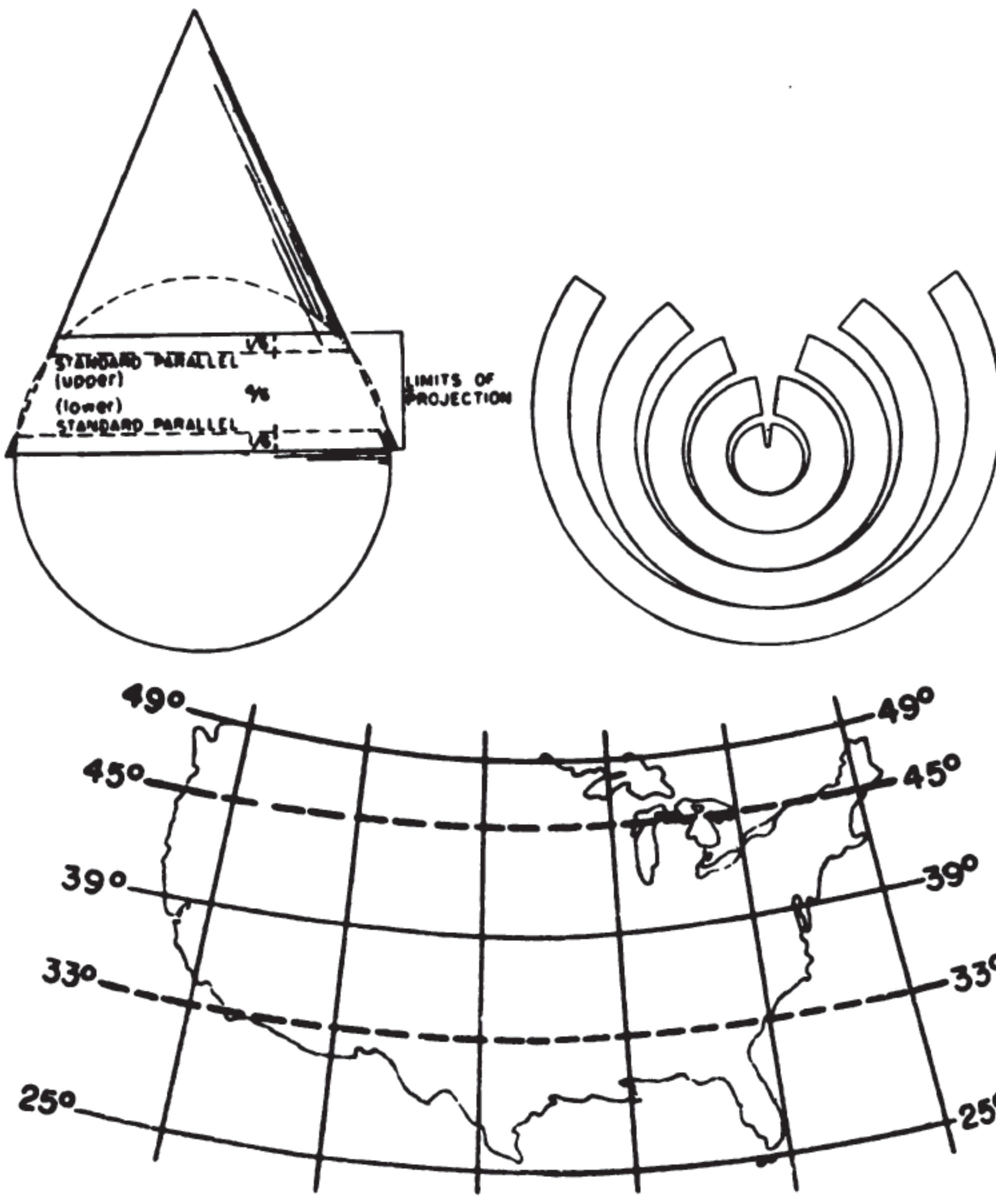


Figure 13–4.—Lambert conformal conic projection.

Conformality (true shape) means that any very small figure on the earth is represented by a similar small figure on the map. For short distances at any place, the scale is the same in all directions, and the angle between two curves upon the earth is preserved in its representation on the map. Therefore, the azimuths of lines on the map are the same as those on the earth. Along any given parallel the scale is constant and is the same in all directions at any given point, but it changes from point to point in any direction except along a parallel. Therefore the magnification at a point is a function of the latitude and is independent of the longitude. When scale error is computed for any parallel, it holds constant throughout that parallel.

The graticule, or projection grid, shows the meridians appearing as straight lines converging toward the pole while parallels are concentric circles that intersect the meridians at right angles.

The advantages of the Lambert conformal conic projection are that:

1. For practical purposes there is only ONE scale for the entire map.
2. All directions within standard parallels are approximately true.
3. Great circles are very nearly straight lines.
4. When applied to large areas of E-W extension or to smaller sections within such an extension, it is remarkably accurate.
5. It is an excellent projection for aeronautical charts.

The disadvantages of the projection are that:

1. When used over wide areas of latitude, it develops serious defects toward the north and south boundaries.
2. Plotting of courses is made somewhat difficult because rhumb lines appear as slight curves. Over long distances great circles are also curved lines.

POLYCONIC PROJECTION

Some original hydrographic surveys are plotted on large scale polyconic projections. In the polyconic projection,

the earth is considered to be a stack of innumerable thin horizontal cone slices. That is, every parallel of latitude is represented on the map by the developed circumference of the base of a right cone tangent to the earth at that parallel. It is apparent that as the parallels approach the Equator, the shape of the cone approaches that of a cylinder and the Equator appears on the projection as a straight line perpendicular to the central meridian. The other meridians are concave curves on either side of the central meridian, converging as they go from the Equator toward the poles. The parallels are spaced on the central meridian true to scale and are drawn through these points with proper radii as nonconcentric circles. Actually, the process of development is to open out each parallel of latitude by itself so that the final plot shows the parallels diverging as they depart from the central meridian of the map.

The advantages of the polyconic projection are:

1. It is a good projection for areas of wide latitude and narrow longitude. Within 560 miles on either side of the central meridian, the error in scale and area does not exceed 1 percent.
2. E-W direction is fairly accurate.
3. There is universal scale (except near E-W boundaries).
4. Calculated general tables and mechanical ease of construction make for great popularity.

The disadvantages are:

1. Distortion of distance, areas, shapes, and directions increase with longitudinal extension of the map.
2. Course lines are incorrect for all but short distances.
3. Compromises between various conditions, such as conformality and equal area, both of which cannot be represented on the same chart, makes it impossible for a neat junction to be formed between adjoining sheets prepared as polyconic projections.

Most original hydrographic surveys are plotted on large scale polyconic projections. The polyconic system was selected by CinCPac-CinCPoa for use on amphibious maps, naval bombardment charts, and air support charts during

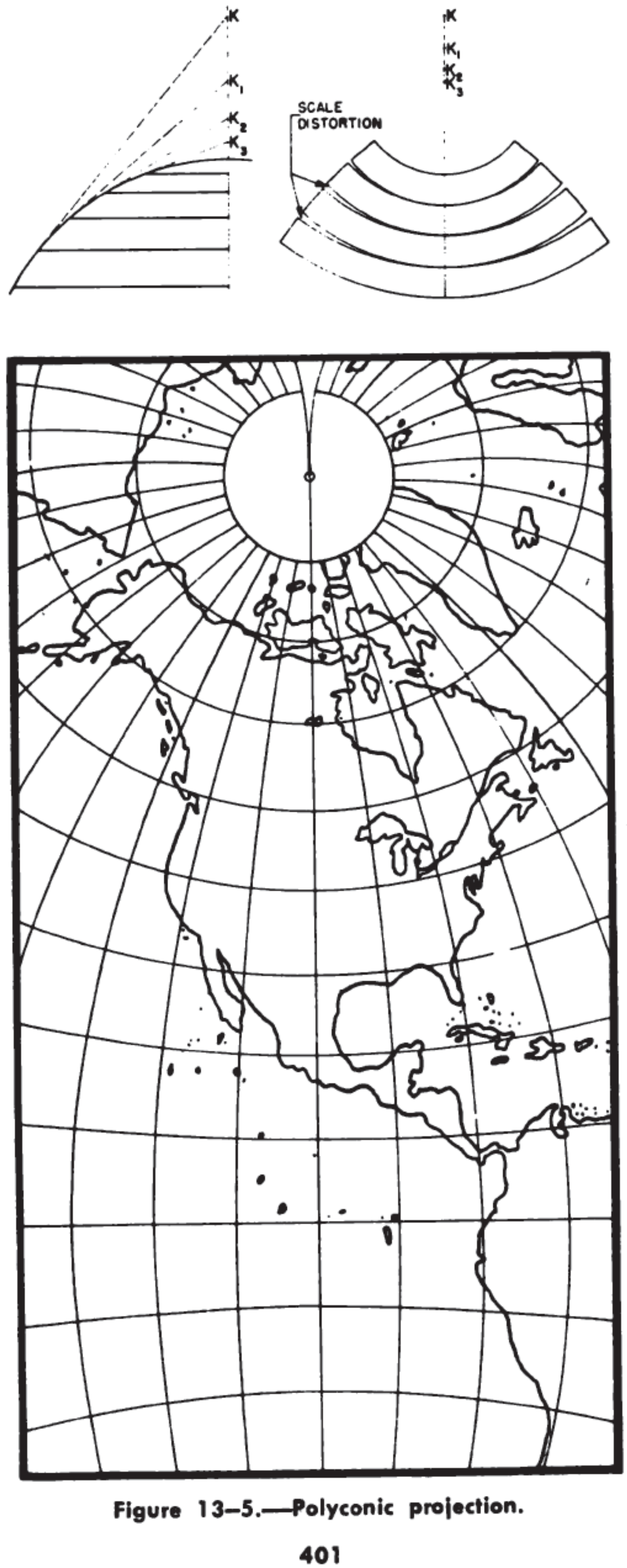


Figure 13–5.—Polyconic projection.

World War II. All of these graphics carried the World Polyconic Grid so that the grid or target area references could be understood by soldiers, sailors, and airmen alike on whatever map or chart they happened to consult (other than basic H. O. charts).

Figure 13–5 indicates the development of the polyconic projection. Actually, the number of cones is very large, approaching infinity.

BORDERS AND SCALES

The border of a chart consists of either a neatline or a border scale defining the limits of the area charted. Outside the neatline, and separated by a space in which the projection figures are placed, are 2 parallel lines, 1 fine and 1 heavy, drawn close together.

On Hydrographic Office nautical charts, there are two types of borders—plan borders and scale borders. The type of border used depends on the natural scale of the chart and is selected according to the rules given in the pamphlet *Nautical Chart Borders and Scales*, H. O. Misc. 11,131. In general, plan borders are used for plans and plan charts with natural scales of 1 : 49,999 or larger. Scale borders are used where the natural scale is 1 : 50,000 or smaller. In exceptional cases, plan borders may be used on charts which are smaller than 1 : 49,999, which are intended for approach or plan charts.

The dimensions of both plan and scale borders are given in figure 13–6. The table indicates the distances in centimeters. The first column in the table gives the number by which the border is designated. This number is arrived at for any chart by multiplying the inner neat line dimensions in inches, the length of the chart by the width. The nearest number to this sum in the table is the number of the border to be used for this chart. For groups of plans, use two-thirds of the sum of the length and width of the chart in inches, after the plans have been grouped. No. 65 will be the largest border to be used and No. 40, with a few exceptions, will be the smallest.

The letters a, b, c, d, e, f, and g heading the columns are used as keys to the dimensions designated in the drawings of the borders. For example, a No. 65 scale border will have a total width of 1.280 cm., which is designated as f in the table and indicated as f on the drawing. Inset plans should be placed at a distance of c, or .529 cm. in No. 40, from the neat line of the main chart.

The placement of degree figures is determined by the size of the chart, which also determines the lettering of minutes and seconds and the subdivision of minutes on plan charts, and the division of the border and lettering of minutes on scale charts.

Graphic scales are added only where a plan border is used, and the type of scale is determined according to the natural

DISTANCES IN CENTIMETERS

No.	a	b	c	d	e	f	g	*2(a+b+c+d)+e Scale border	*2(c+d)+e Plan border
65	.116	.116	.741	.180	.127	1.280	1.048		
60	.106	.106	.698	.169	.127	1.206	.994		
55	.106	.106	.646	.169	.127	1.154	.942		
50	.095	.095	.614	.159	.116	1.079	.889	2.042	1.662
45	.095	.095	.572	.148	.116	1.026	.836	1.936	1.556
40	.074	.074	.529	.148	.106	.931	.783	1.756	1.460
35	.074	.074	.487	.138	.106	.879	.731		1.356
30	.064	.064	.444	.127	.095	.794	.666		1.237

*Distance between inner neat lines of borders for grouping of plans

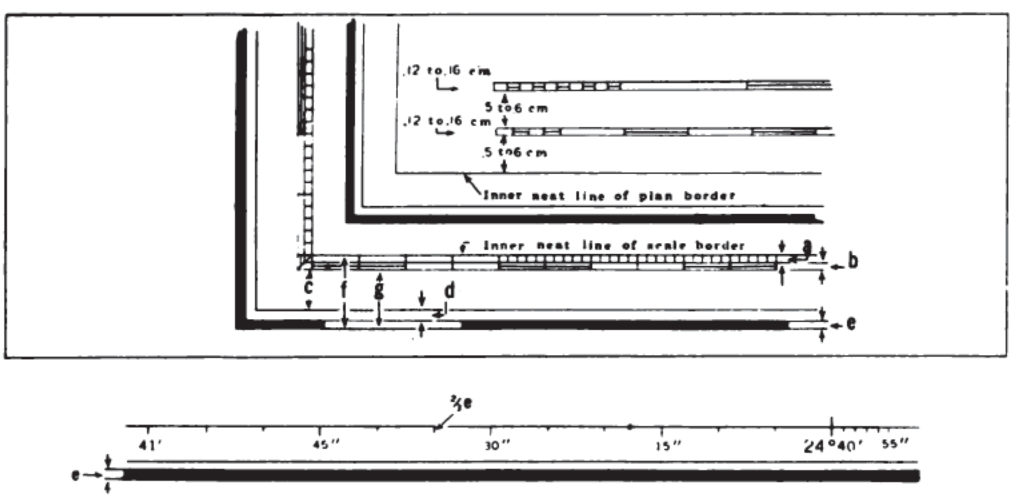


Figure 13–6.—Dimensions of scale and plan borders.

scale of the chart. The number of miles, yards, or meters shown are determined with consideration for the amount of space available and the over-all size of the plan or chart. Nautical mile, yard, and meter scales will be placed on all nautical charts and plans with plan borders, except that where 1 nautical mile equals 6 inches (15.24 cm.) or more or where the space for scales is limited on small plans, the nautical mile is omitted.

At the Hydrographic Office, the scale border for a chart is usually inked directly by using the Border Scale Subdividing Device. If this device is not available, it is best to draw the border carefully in pencil, with the aid of dividers, before inking it.

The outer black lines of both the scale and plan borders are drawn with a ruling pen. First, the outer limits, or boundary, of the line is drawn, and then the setting of the pen is widened and interior lines are drawn successively until the proper width is achieved.

Constructing Plotting and Conversion Scales

The plotting scale shown in figure 13–7 contains 2 full 1,000-foot units and 1 subdivided 1,000-foot unit at a natural scale of 1 : 5,000. First the exact length of the line AE was calculated, thus,

$$AE=\frac{3{,}000 \text{ x } 12}{5{,}000}=7.2 \text{ inches.}$$

The 3,000 is the number of foot units; 12 the number of inches in a foot; and 5,000 the number of feet on the scale to be represented by 1 foot.

Then this line AE is drawn, and 10 lines the same length are drawn parallel to it, each 0.2 inch from the next. To divide the line AE into the 3 equal parts, each representing 1,000 feet, draw a line similar to AB. Lay off any convenient length three times on this line. Connect the last point with E by drawing a fine line, and parallel to this, draw 2 more fine lines, cutting the line AE, from the other 2 points on AB. Now from the points thus obtained on AE and from point A and point B, draw perpendiculars con-

necting the 10 parallel lines previously drawn. Label the lower ends of these lines 1,000, 0, 1,000, and 2,000.

Divide CO into the 10 equal parts, using the same method by which AE was divided into 3 equal parts. Extend the divisions for CO to the corresponding parts of the line AO'. Connect diagonally each division point on AO' with the preceding division point on CO as shown in figure 13–7. The finished inked scale should show only the solid lines and numerals indicated in the figure.

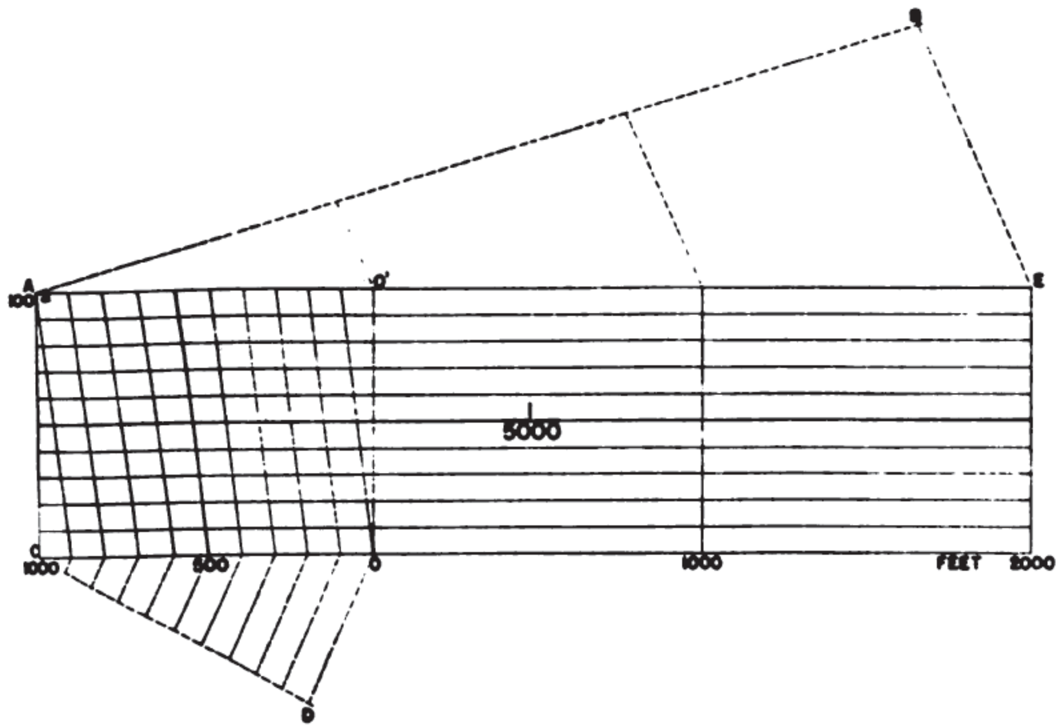


Figure 13–7.—Constructing a plotting scale.

To construct a plotting scale 1:40,000 to read to 10,000 yards, first draw the parallel horizontal lines, as shown in figure 13–8. Since the scale is to read a maximum of 10,000 yards, the length of the lines will be:

$$\frac{10{,}000 \text{ x } 36}{40{,}000} = 9.0 \text{ inches.}$$

Divide lengths of the lines into ten 1,000 yard parts by the vertical lines as shown. Then subdivide the left rectangle

at top and bottom into 10 equal parts and connect the divisions with parallel diagonal lines as shown. Finally draw the numerals on the scale.

The plotting scale is used like the meter bar. Note that the slanted lines on the portion of the scale falling to the left of the line 0 intersect the horizontal division lines on the face

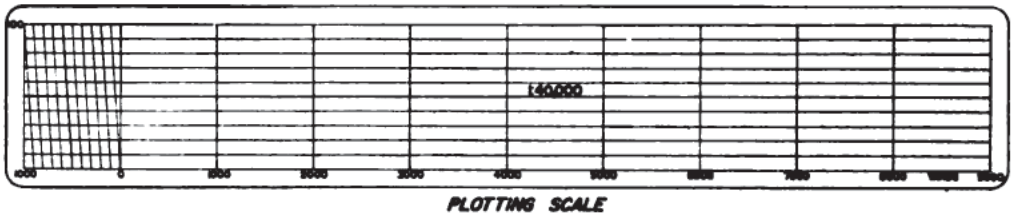


Figure 13–8.—Plotting scale 1: 40,000 to read to 10,000 yards.

of the scale. On the line from 0 to 1,000, each of these lines marks a 100 division point. For example, reading from 0 to the first division to the left, you get 100. If you follow this line up to its intersection with the first horizontal line, you get 110. The intersection with the second horizontal line marks the 120 mark, and so forth. The other lines provide the same method for dividing the unit of measurement into tens. For example to find 600, count to the left 6 divisions from 0 and then up to the 6th intersection on the slanted line marking that division. On the meter bar, of course, the unit of measure is in meters rather than in feet.

Figure 13–9 illustrates conversion scales at a natural scale of 1:20,000 showing relative values for miles, yards, feet, meters, and kilometers to read 6,000 yards. To construct these scales, first calculate the length of 6,000 yards at a scale of 1:20,000, thus,

$$\frac{6{,}000 \times 36}{20{,}000} = 10.8 \text{ inches.}$$

Lay off the 10.8 inches on the scale which is to represent the measurements in yards. Divide this distance with six 1,000-yard parts and then divide each 1,000-yard part into ten 100-yard parts. Now, using this yard scale, divide the line representing measurements in feet into eighteen 1,000-

foot divisions and then divide each of these into ten 100-foot parts.

On the mile scale, mark opposite 1,760 yards the first mile, and then make two more marks for the second and third mile as shown in the figure. Divide each mile into 4 parts and label the ¼, ½, and ¾ points in the first mile. On the meter scale, next to the foot scale, mark every 1,000-meter mark, the first opposite 3,280 feet and the others at multiples of this figure. Divide each 1,000 meter into ten 100-meter

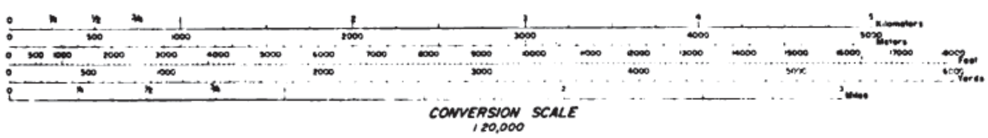


Figure 13–9.—Conversion scales.

units. On the kilometer scale mark every kilometer opposite each 1,000-meter mark of the meter scale, and subdivide each kilometer into ¼, ½, and ¾ parts by utilizing the 250, 500, and 750 meter marks on the meter scale. Add all lettering, numerals, and marginal data. Ink the sheet and erase pencil lines and smudges with art gum.

STEPS IN MAKING A CHART

There are a number of methods for constructing a chart. As listed in *Modern Cartography*, published by the United Nations in 1949, those normally used are:

1. Copper engraving;
2. Glass engraving;
3. The Duco method;
4. The plastic method.

In the copper engraving method, the work is done either entirely by hand, or by a combination of mechanical and hand engraving. The outstanding instrument for mechanical engraving on copper is the pantograver developed by the U. S. Navy Hydrographic Office. In the glass engraving process, both the mechanical and hand engraving procedures are utilized. The system used by the U. S. Coast and Geo-

detic Survey is described in its pamphlet *Glass Negative Engraving* by Mr. D. P. Barnette, published in 1948.

Glass engraving is also used by the U. S. Lake Survey in combination with the pantograver which has been modified for that purpose. Both methods are very effective and produce a sharp original.

At the Hydrographic Office either the DUCO or the plastic method may be used. Usually a compilation mosaic is made first, either from original surveys or from existing foreign charts. Figure 13–10 shows a portion of such a mosaic.

The topographic material for the east and west end of the island was obtained after the mosaic was completed which accounts for the void in the mosaic. At the Hydrographic Office, all originals of nautical charts are done at 1 to 1 scale. That is, charts are reproduced at the same size at which they are executed. On the other hand, development plans or plates prepared for the Bureau of Yards and Docks or cartographic work done for other bureaus may be enlarged or reduced to fit a standard format.

Work is done on both sides of a compilation mosaic. First, a true Mercator projection is computed and drafted in pencil at the scale of the finished chart on the front (F) side of the transparent plastic. These projection lines are used for plotting horizontal control and for orienting the film positives of the source material. The projection lines are then drawn and the horizontal control plotted and numbered in blue ink on the back of the sheet.

On the front of the sheet, the limits of the Mercator projection, or the rectangle, and degree and minute figures are drawn in black ink. Three thin coats of a liquid adhesive are then applied by a spray gun. The adhesive now used requires 30 minutes of drying time, but will remain tacky for a long time thereafter. A thin piece of acetate or cellophane may be placed in contact with the adhesive to protect the front from dirt, and later removed, and the film positives applied without the adhesive having lost any of its tenacity.

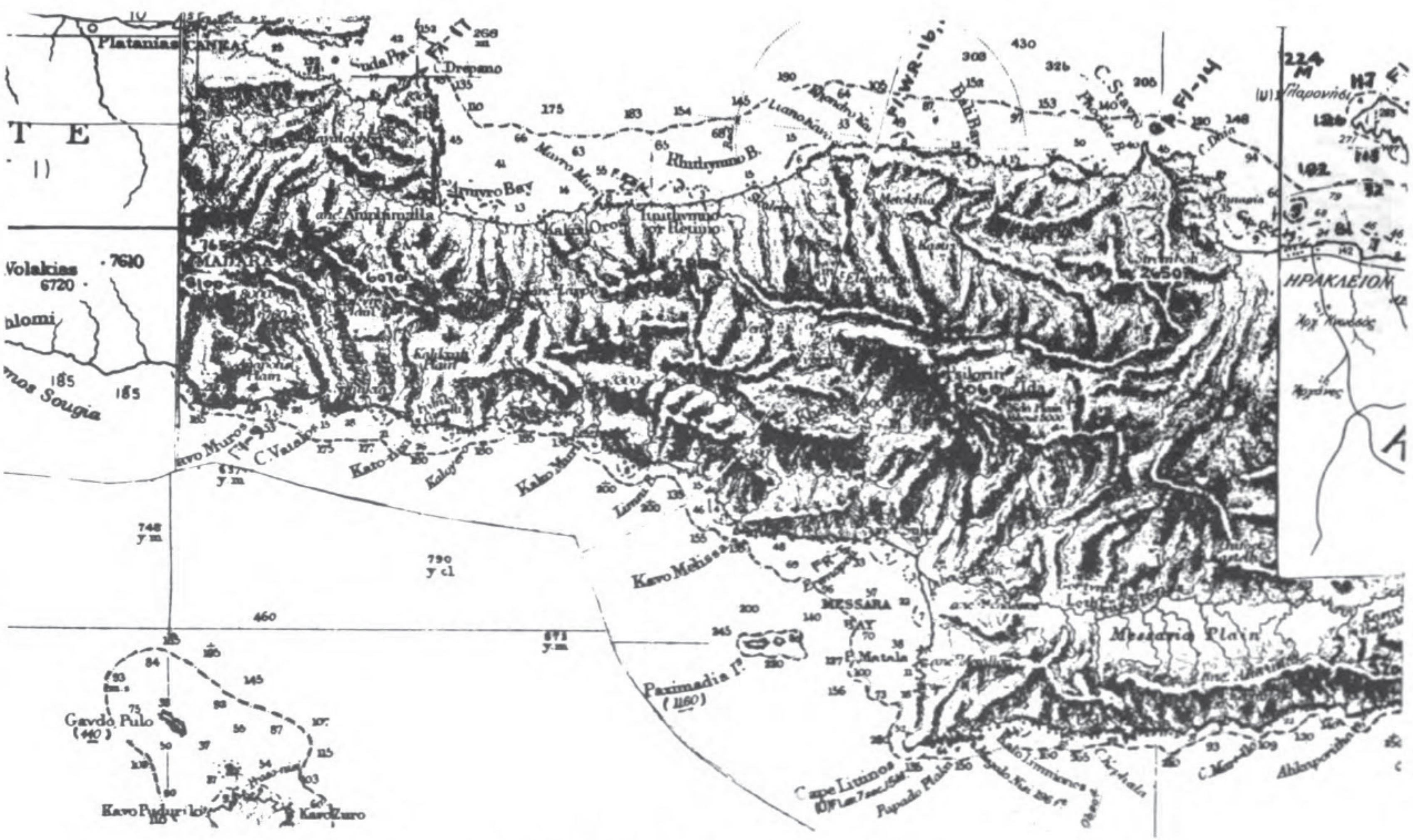


Figure 13–10.—A compilation mosaic.

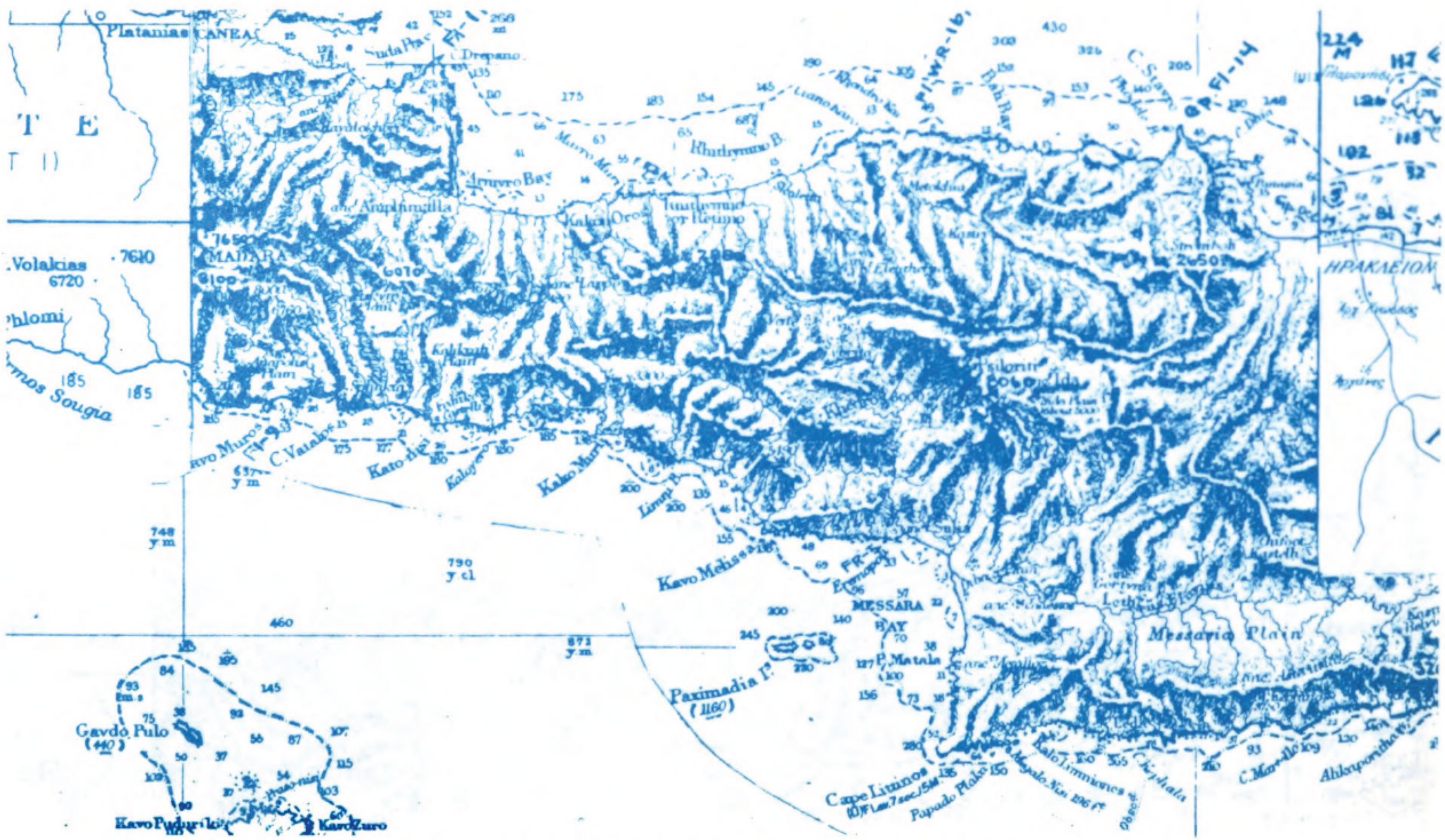


Figure 13–11.—Blueline print made from the compilation mosaic.

Distortion in the source material is reduced to a minimum by cutting the film into small pieces.

When the mosaic is completed, deletions and corrections are made, additional information is added, and the broken lines are joined. Then a contact film is made of the mosaic. At this point, the mosaic includes everything that will be shown on the final lithographic print, except such material as magnetic variations and compasses.

For the chart shown in figure 13–11, four specification sheets were made as blueline prints. One of these was marked up and served as a general layout sheet indicating the essential topographic and cultural features, all necessary measurements in centimeters, the placement of the titles and all necessary notes, the type of scale border, and the position of drawn projection lines; the hydrography—sounding figures and fathom curves—was indicated on the second sheet; the essential names and size of type faces on the third; and the fourth was used to indicate the decisions of the Board of Geographic Names for spelling.

The drafting medium on which the negative is printed in blue lines is usually an opaque plastic. Before plastics were available, Duco was generally used. Duco is a grained zinc lithographic printing plate which has been sprayed with enamel paint, producing a matte surface. A laminated paper may also be used. Whichever medium is used, the draftsman inks with black ink the material to appear on the final chart. When the inking is completed, this chart original is stored with a duplicate of it which is made photographically.

The chart original serves as the base black and contains all the topographic and hydrographic information plus the type. Figure 13–12 reproduces both unfinished and finished stages of the drawn original of the same chart shown in figure 13–11. The unfinished lines would be blue and the type would be stickup on the actual chart.

The chart original is ultimately photographed on a glass

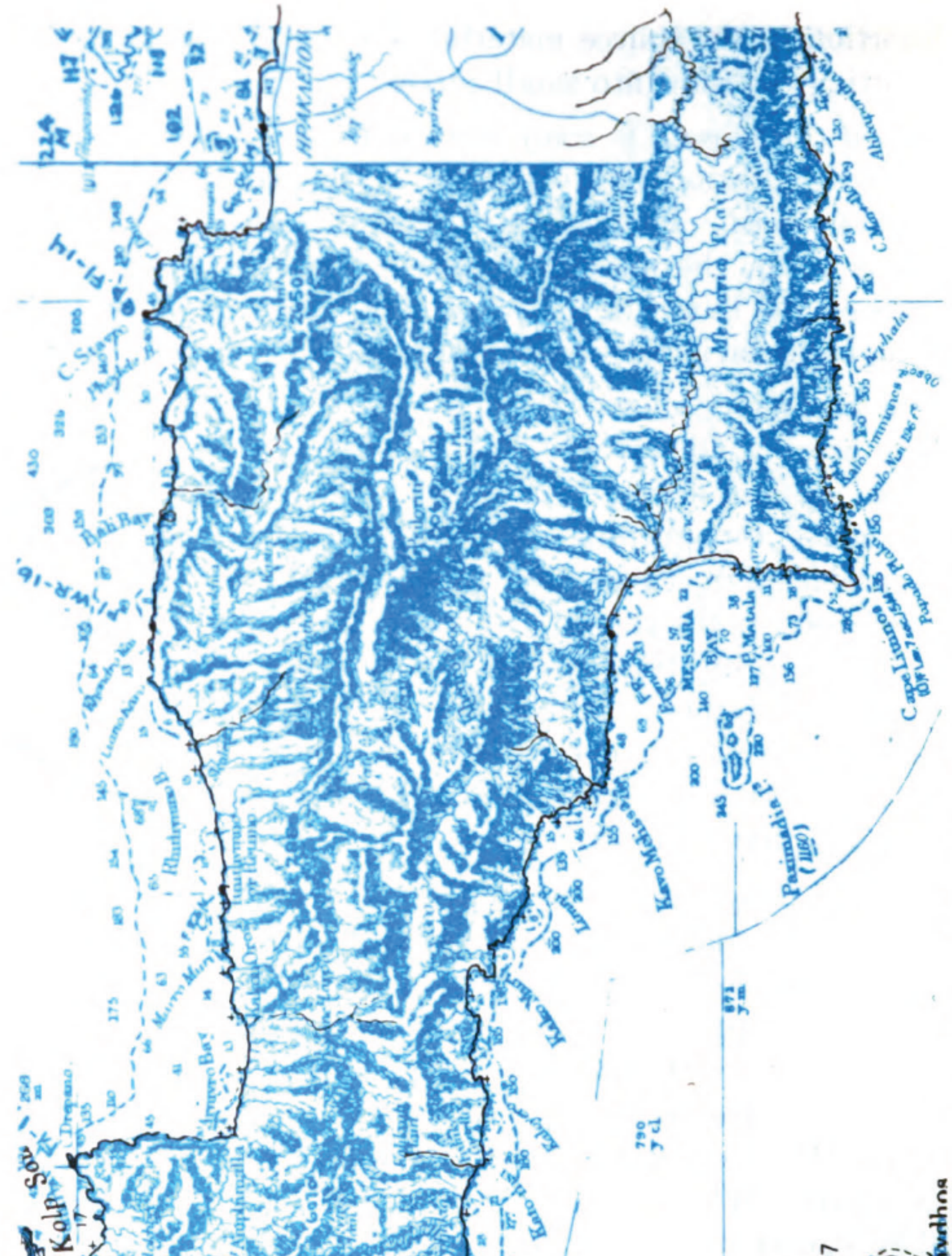


Figure 13–12.—A. The unfinished chart original.

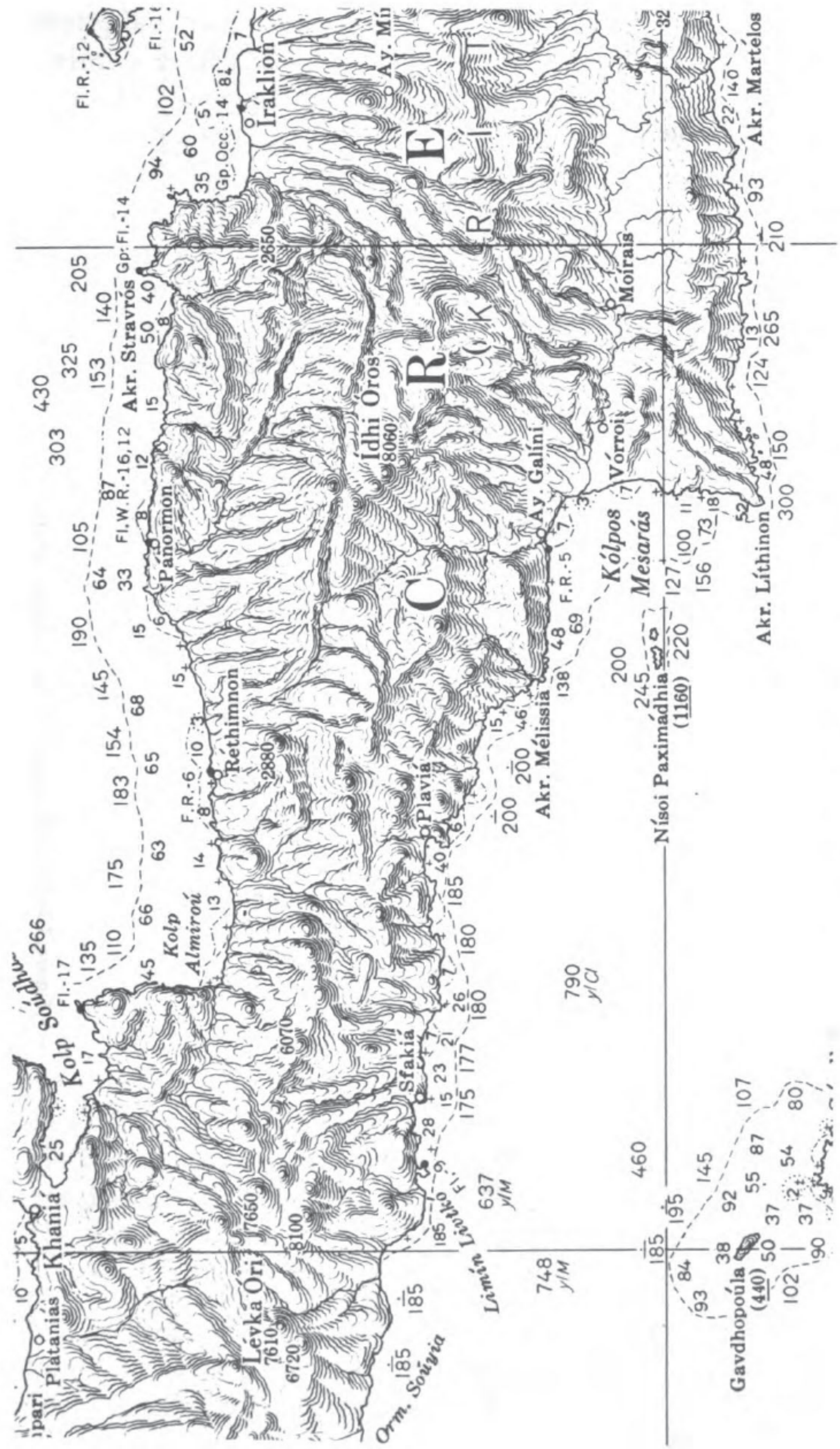


Figure 13–12.—B. The chart original.

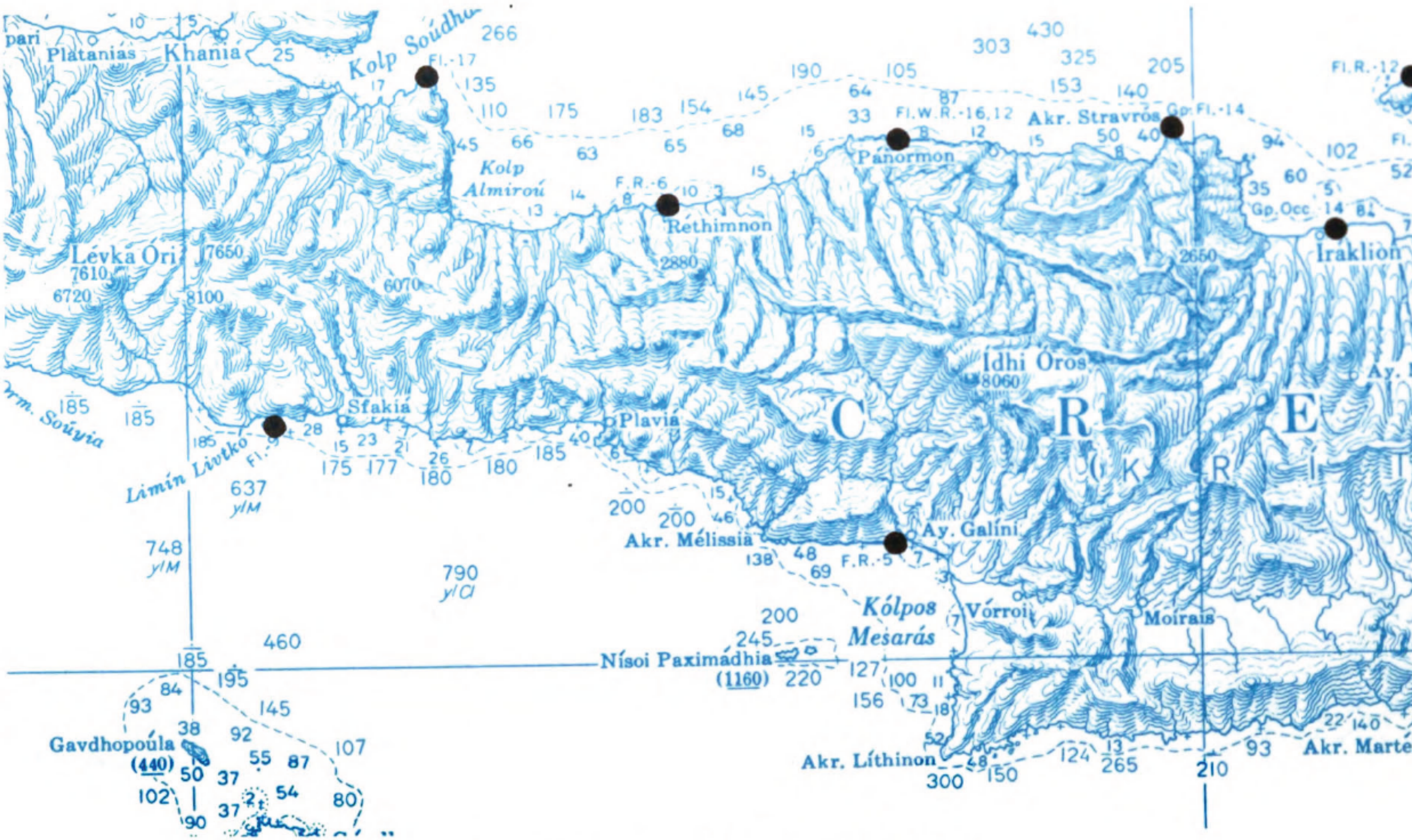


Figure 13–13.—Original for the magenta plate.

wet plate negative, and from this negative, the following prints are made:

1. A blue-line opaque plastic on which the draftsman draws the light circles and the compasses and which will serve as the original for the magenta plate. (See fig. 13–13.)
2. A print in black on photographic paper for editing.
3. A print on photographic paper to be marked as a color guide for the land and blue area, which is used by the lithographic draftsman in making color plates.

TOPOGRAPHY AND HYDROGRAPHY

In the production of modern charts, the data concerning topographic and hydrographic features may be obtained from several sources. The most accurate details are obtained from topographic and hydrographic surveys, made by such methods as those described in chapter 12. The data from a number of surveys may be correlated with material from old charts, and supplemented by aerial photographs.

Aerial photography reading is a specialty in itself. The Army has published several manuals on the interpretation of aerial photographs and many of the chapters in TM 5-230, *Topographic Drafting*, published by the War Department in 1940, are concerned with methods of using aerial photographs in making maps, as well as photographic mosaics. The Hydrographic Office has published a *Manual of Coastal Delineation From Aerial Photographs*, H. O. Pub. No. 592. This publication is chiefly concerned with the types of coast line, how they evolve, and what navigational hazards may be expected with each type. One section of the manual consists of stereo pairs of vertical photography of various coastal features, with examples of delineation of these features on the photographs.

Plotting

The first step in plotting a chart consists of plotting the control. There are two general classifications of control insofar as a hydrographic survey is concerned. The control

stations must be plotted with the utmost care and accuracy, since inaccuracies in their positions may result in errors in the positions of the soundings, the errors increasing with the distance from the control stations. Stations whose geographic positions are known should be plotted with an accuracy that will ensure no plottable error at the scale of the chart.

The *Hydrographic Manual*, Special Publication No. 143 of the Coast and Geodetic Survey, includes a section on the different types of shore and floating control and methods of plotting them on the smooth sheet, which is the final record of a survey sent to the Washington office. The *Interim Photographic Interpretation Handbook*, NavAer 10–35–500, contains valuable material on annotating and correcting charts from photographs. Especially on aircraft carriers, a draftsman will be expected to work from photographs of an area to make overlays and annotations which bring an existing chart up to date. The importance of this work can scarcely be overemphasized, since the success of an air strike may depend on the skill of the draftsman.

The topographic detail may be transferred to the chart by a number of methods, depending on where the work is being done and the degree of finish and accuracy required. Along with the control, the detail may be reduced to the desired scale and transferred photographically, or it may be transferred by the use of tracing paper, a projector, a pantograph, the method of squares, or the radial line method. The last is the least desirable in that it is of value where only an approximate accuracy is required.

Symbols

On small scale charts, few symbols are shown, but on large scale charts used for piloting ships into harbors or for landing operations, the use of symbols to indicate hazards is of great importance. The basic symbols used by the Hydrographic Office, the Coast and Geodetic Survey, and the Lake Survey are given in *Nautical Chart Symbols and Abbreviations*, No. 1, published by the U. S. Coast and Geodetic Sur-

vey. Other symbols may be found in the AMS Technical Manual No. 23, *Symbols for Large Scale Maps*, published by the Army Map Service and in FM 21–31, *Topographic Symbols.* Special military symbols have been published by the Army in FM 21–30, AFM 55–3, *Military Symbols.*

At the Hydrographic Office most of the common symbols are available printed on thin plastic sheets backed with an adhesive. These may be applied to the chart in the same manner as lettering, saving considerable effort on the part of the draftsman.

Soundings and Fathom Curves

A sounding is a measurement of the depth of water which is expressed in feet or fathoms and reduced to the tidal datum shown in the chart title. On small scale charts, the soundings are shown in fathoms, while on large scale charts and plans of rivers and harbors, they are generally shown in feet. However, when river banks, reefs, and rocks are uncovered by tidal fluctuations their height above the chart datum is always shown in feet with the figure underlined. Soundings are represented on the chart by vertical hairline figures centered both vertically and horizontally over the position of the sounding. The sounding usually consists of two figures and thus the position may be assumed to be at the center of the space separating them, regardless of whether one of the figures is 1 or a wider digit such as 6. The position of a three-figure sounding is at the center of the middle digit. (See fig. 13–14.)

Before the development of the modern echo-sounding devices, sounding apparatus often failed to reach bottom. In that case, a no-bottom sounding was recorded in this manner: $\dfrac{\cdot}{200}$. This particular figure on a chart would mean that the depth was at least 200 feet or fathoms, depending on the unit of measurement being used. You may find a sounding recorded in such a manner on old charts.

The selection of soundings for chart construction requires a careful study of available data in order that all known dan-

gers to navigation may be clearly developed and their least depths plotted. The spacing of soundings is variable, depending on the depth of water and character of reefs, shoals, and banks. In general, the soundings are more closely spaced inshore and around dangers, gradually increasing the spacing as the water deepens offshore. The selection of only

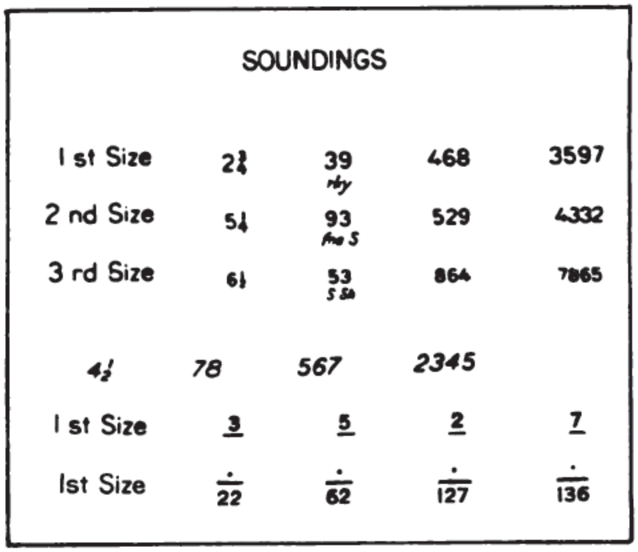


Figure 13–14.—Specimen soundings in the various gages.

the least depths should be avoided, since representative soundings are desired in order to furnish the navigator with a true picture of the bottom variations.

Bottom characteristics are added beneath soundings to 100 fathoms and abbreviated in accordance with the Hydrographic Office standards. They serve a very useful purpose for a navigator by enabling him to judge the holding ability of the ship's anchors, as well as his course of action if he runs aground.

Outer soundings of equal depth are joined by FATHOM CURVES similar to land contour lines and serve to emphasize channel areas and obstructions of navigation. Great care must be exercised in plotting these curves, as their omission in critical areas may have serious results, especially if this causes certain rocks or shoals to fail to be emphasized. Those curves usually selected for plotting are the 1, 3, 6, 10, 20, 30,

50, 100, and 1,000 fathom curves. The change to a 6-fathom curve in place of the 5-fathom has occurred because ships are larger and draw more water.

Contour lines beneath the surface of the sea are called BATHYMETRIC CURVES. They are like fathom lines except that they are drawn at even contour intervals. Special purpose charts for planning purposes and positioning where it is not possible to get an electronic fix are prepared with these lines. They are drawn as contour lines are drawn on land maps and are usually shown in blue. Bathymetric form lines are solid lines drawn on a chart to outline various depth layers in a general way. Where the locations for these form lines are known, they are drawn in solid lines, otherwise they must be interpolated and shown by dashed lines.

Elevation and Relief

Land forms and prominent peaks are often used by the navigator as an aid to navigation, both visually and with radar. Therefore on hydrographic charts, as well as on aeronautical charts and land maps, the elevations and relief forms of the land are important. The elevations are given in relation to a datum plane. On H. O. Charts, the datum is included in the legend which accompanies the title of the chart. The elevation of all mountain peaks shown on a chart may be given in feet above some mean, generally high water or mean sea level (MSL).

Since survey data from some areas is scarce or nonexistant, it is not uncommon for land areas to appear blank on the compilation for nautical charts. When relief is included on the unsurveyed areas of such a chart, several methods may be used to give a fairly accurate impression of the land forms. Each method is generally used alone but occasionally two of the methods are combined. The method or methods selected must show three things: (1) the terrain characteristics (shape and size of the hills, ridges, valleys, etc.); (2) the steepness of slope; and (3) the height of the prominent features.

HACHURES were the first form of relief in which an attempt

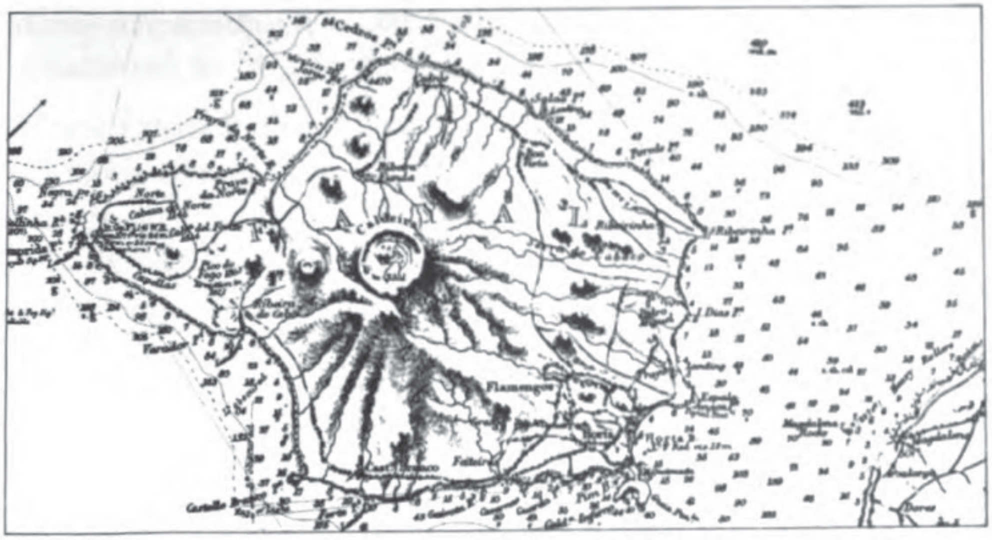
was made to show the true location and shape of individual land forms, as well as to employ a three-dimensional effect. The maps were engraved in great detail from source material such as sketches, drainage, spot elevations, and land descriptions. Although the art is too costly and time consuming for modern reproduction methods, the maps incorporating it are invaluable as source material and, in many cases, the hachuring on them is reproduced on modern charts.

As finally developed or drawn, the relief consists of short shade lines running directly down the slopes of the hills. The slope of the hill is indicated by the thickness and spacing of the individual hachure lines. A steep slope is indicated by heavily inked lines close together. Light shaded portions are gentle slopes. Level areas are left without shading. Hachuring is very common on European maps, although it is not used on modern maps, except reprints, having been superseded by other methods. Figure 13–15A shows a section of a British Admiralty Chart with the relief shown by hachuring.

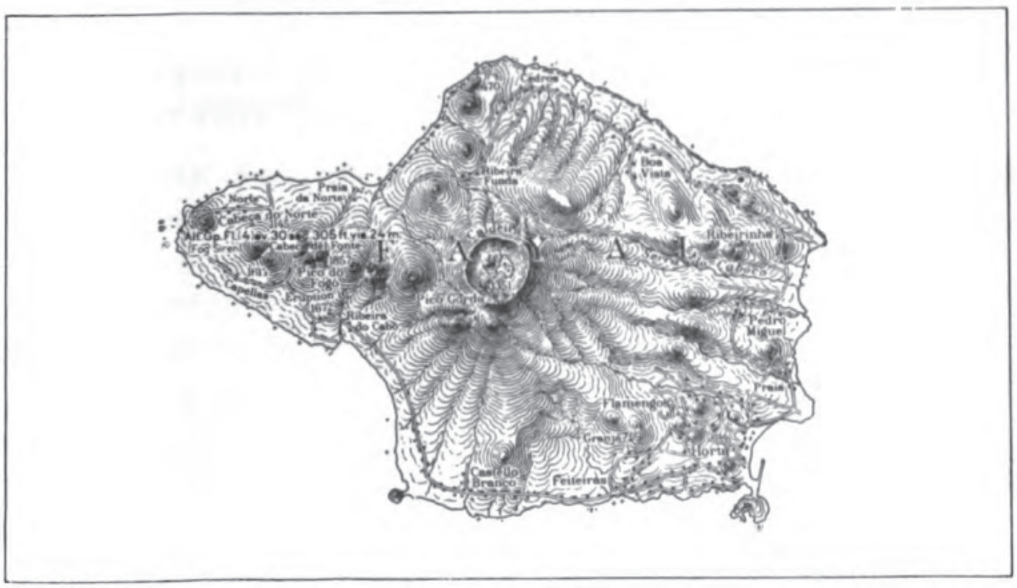
The chief disadvantages of hachuring, from the point of view of the draftsman, are the skill and time it requires. The width of the lines and the consistency of the pattern are extremely difficult to maintain, and there are few draftsmen with sufficient skill to do hachuring rapidly.

The method of CONTOUR LINES has the advantage of being the most accurate means of depicting relief because each point on a line represents points of equal elevation on the earth. All photogrammetric plotting devices which depict elevation forms delineate contour lines or approximate contours.

Generally, every fifth contour line, called an index line, is numbered according to its elevation, usually above sea level, and this line is always heavier. The elevation of a contour must always be divisible by the contour interval. The contour interval is the amount of elevation between lines. Usually, the contour interval is given on the margin of the map. Elevations of hill tops are shown by a dot and the figures for the height.



A



B

Figure 13–15.—A. Section of a British Admiralty Chart with relief shown by hachuring. B. As redrawn by the Hydrographic Office with shaded form lines.

The contour-line method has certain disadvantages. Without experience or training in reading contour-line maps, a man will find it difficult to visualize the shape of the ground. Contour lines are a precise representation of relief, but they do not readily give a visual picture of it. Also, contour lines are always drawn as smooth curves, whereas

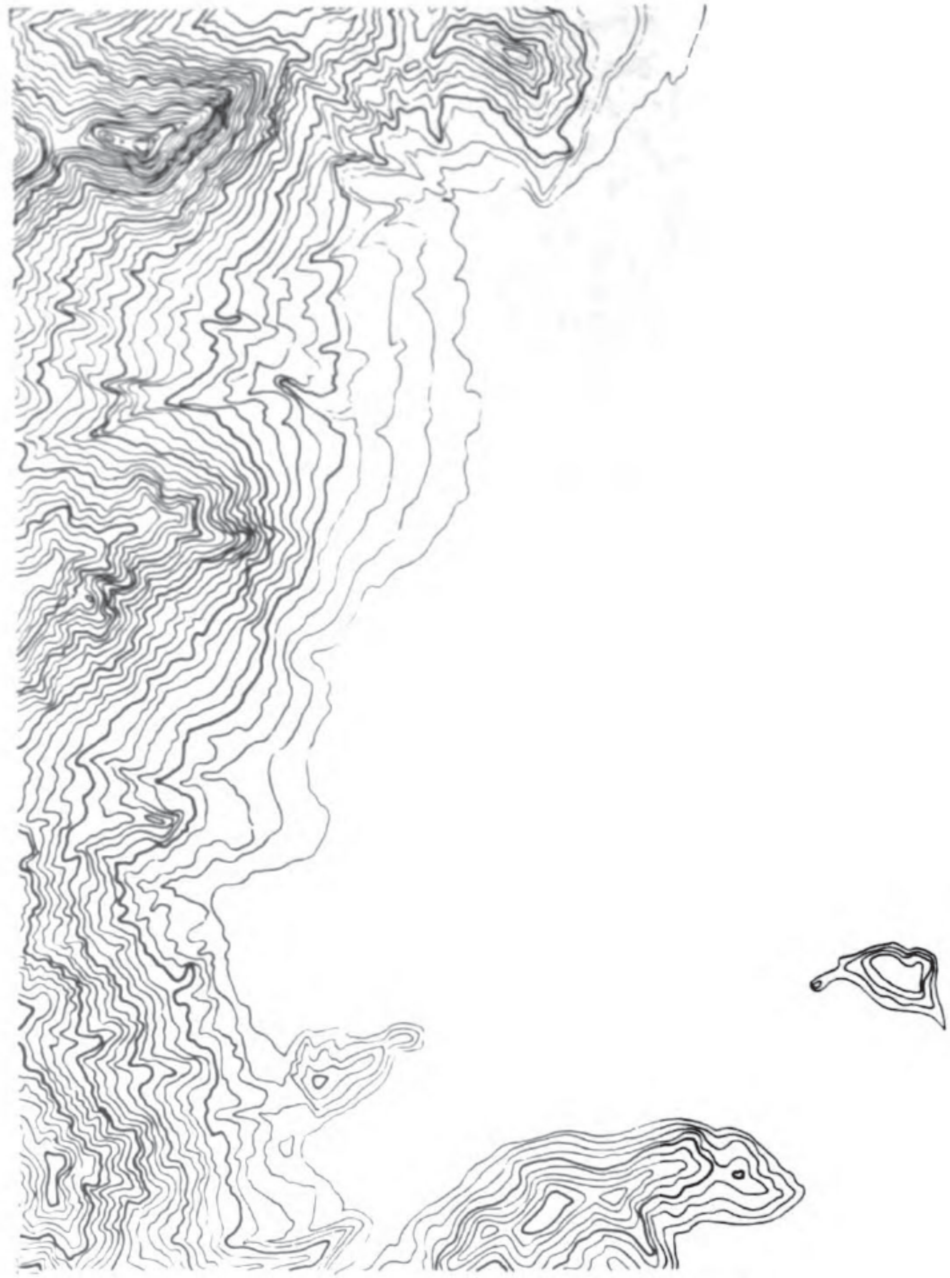


Figure 13–16.—Section of a contour-line map.

the actual texture of the earth may be quite broken. In other words, they are stylized representations of the contours of the earth. (See fig. 13–16.)

Dashed contours are often used to indicate a lesser degree of accuracy than regular contours but a greater degree of accuracy than form lines. These indicate the elevation of the index curves as well as spot elevations. The spot ele-

vations are assumed to be accurate and the curve elevations are assumed to be approximate.

Form lines look like contour lines, in that they are drawn as smooth curves, but no index or heavy line is given. All lines are the same weight, and the elevations of the lines are approximated elevations. Often contours of doubtful or proven inaccuracies will be shown as form lines, indicating a lesser degree of accuracy than contours or approximate contours. The top elevation is generally shown by a dot and figures giving the height, which is accurately determined, but numbering of the curves is omitted. This method does not lend itself to a good visual picture of the terrain, although it is often used with shading so that a pictorial effect is obtained. The form of relief depiction may vary from near contour accuracy to a very sketchy repersentation designed to show no more than general shape.

Hillwork is the name which the Hydrographic Office uses for its most common methods of showing line relief. Actually, there are two types used, shaded form lines, which have a controlled line count, and shading, which is made artistic with no line count. Both depict terrain in a pictorial fashion, more nearly as it actually looks to the eye or on photographs than can be done with contour lines or form lines. Although this type of work has an artistic flavor, the technique can be mastered by adherence to standard principles of shading plus fairly standard inking techniques, provided the principles of contouring and terrain form are mastered.

The representations are very carefully developed from compilations of all types of source material and aerial photographs. Spot elevations are located accurately. Intermediate heights are only approximate, but often the shaded form lines represent contour values.

Shaded form lines were developed at the Hydrographic Office because they were less costly and time consuming to produce than either hachuring or the more accurate contour

lines, while at the same time, they give a visual picture of the terrain. (See fig. 13–15B.)

In appearance, shaded form lines differ from contour lines in two respects. Whereas contour lines are drawn as lines of even weight, shaded form lines are drawn with dark lines on the southeast side of each slope, which taper to very faint lines on the northwest side and may even be dropped out altogether. Also contour lines are drawn with smooth stylized curves, while shaded form lines are drawn with slightly irregular lines. Actually there is a third difference which is not immediately discernable. With contour lines, each line is treated as a whole, as if the earth were constructed of layers. With shaded form lines, each land form is treated as a whole instead, and the lines of one land form do not necessarily join with those of another. This tends to emphasize the real form of the land, rather than the layers of elevation.

SHADED RELIEF gives the best visual picture of the terrain. With this method as with shaded form lines, the source of light is imagined as being in the northwest, so that the southeast slopes are dark as in shadow and the northwest slopes are light. In the Northern Hemisphere, the light actually comes from the south. But for optical reasons, the mountains appear as valleys if the light falls from behind the spectator. If you turn figure 13–17 upside down, you will see how this works.

In the past, both shaded form lines and shading had a disadvantage in that most of the detail was lost on the northwest or light slopes. However, recently a method has been developed at the Hydrographic Office of working on a gray surfaced white plastic sheet to produce a color tint shading with detail on the light slopes as well as on the dark. The dark sides are drawn in with a black hard wax pencil, while the gray surface of the sheet is shaded in reverse by use of metal scrapers and erasers on the light side. This is much the same as a scratchboard technique and permits a greater variation of value on that side.

Shading is printed in color as a halftone and is often com-

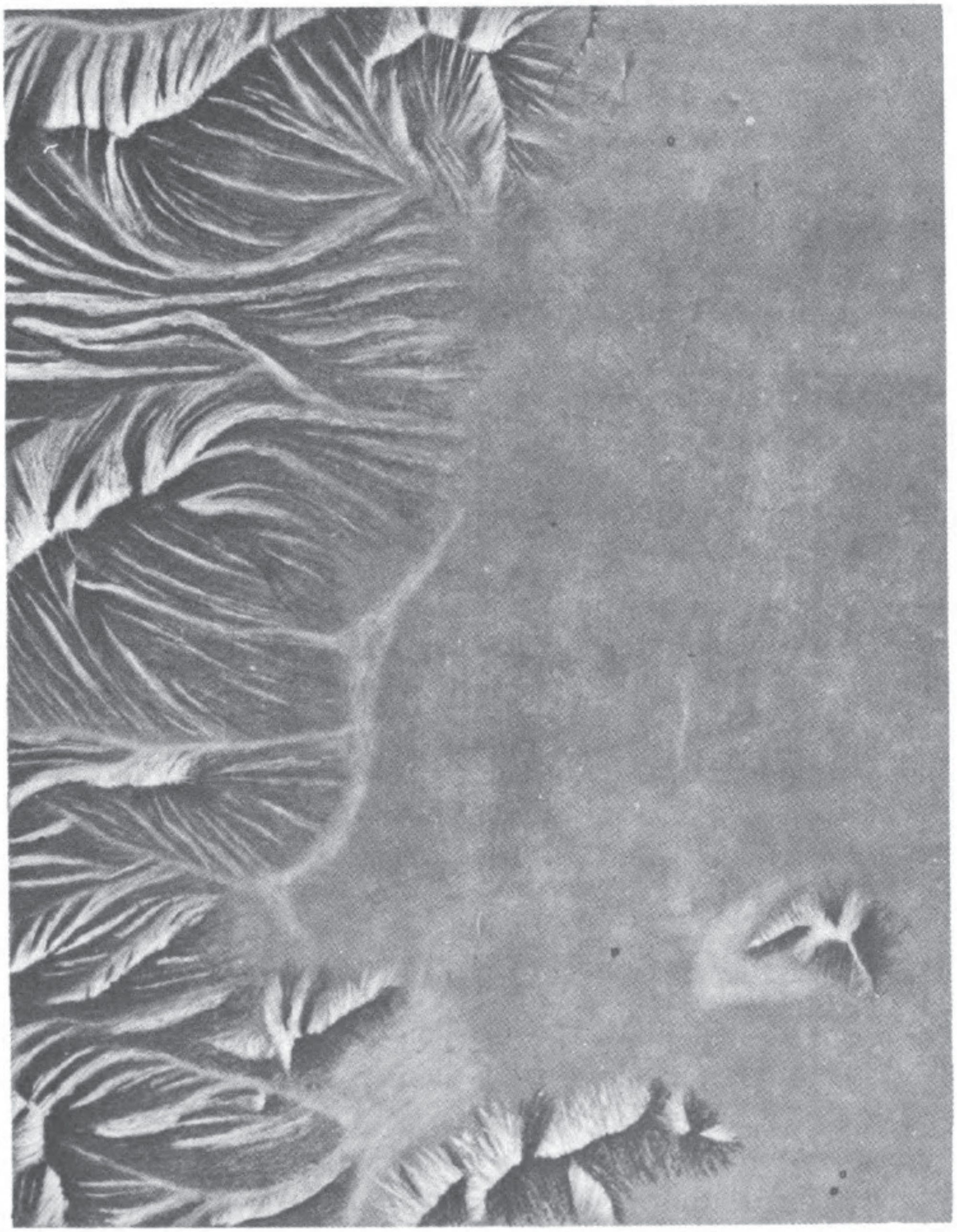


Figure 13–17.—Plate for a shaded map.

bined with contour lines to produce maps that are both visually effective and extremely accurate. Tint shading is sometimes called plastic relief in commercial texts, but the development of a new process of molded relief on plastic sheets makes the term plastic relief seem inappropriate to the older method. All relief shading is most effective when the dark-

est shading is placed on the highest elevations and tapers to lighter shades at the lower elevation.

On first glance, MOLDED RELIEF seems the most effective method which has yet been devised of showing the shape of the land. A molded relief map is made by building up a relief model of the land. A mold is then made of this model, and a plastic sheet, previously printed with the map, is pressed into the mold. The plastic stretches, and the result is a three-dimensional map of the region.

However, the method has several disadvantages. In addition to being expensive, the maps are bulky and take up far too much space to be considered practical for shipboard use. Also, to remain effective, a vertical exaggeration must be employed at the smaller scales. As contours have a horizontal measurement, as well as vertical measurement, the vertical stretch and exaggeration distort the contours which are printed along with all other topographic detail on the sheet prior to the molding process. This causes the contours to seem to run up the sides of slopes instead of remaining level. Because the plotting of bearing lines, etc., is impossible on the irregular surface, the main use of the relief model is limited to terrain studies.

Method of Drawing Contour Lines

Figure 13–18 shows the method by which a draftsman draws contours on a map when he is given the drainage net and the elevations for certain critical points. Drawing of logical contours provides valuable practice in gaining ability to visualize ground forms shown by contours on topographic maps. The information shown in the top section of figure 13–18 has been obtained by a field survey or other means. This information consists of the courses of the stream lines and elevations of selected critical points and forms the framework upon which the contour map is drawn.

Note the stream line shown running from elevation 97 toward elevation 133 in the lower right portion of the figure. In the middle section of figure 13–18, elevations 100, 110, 120,

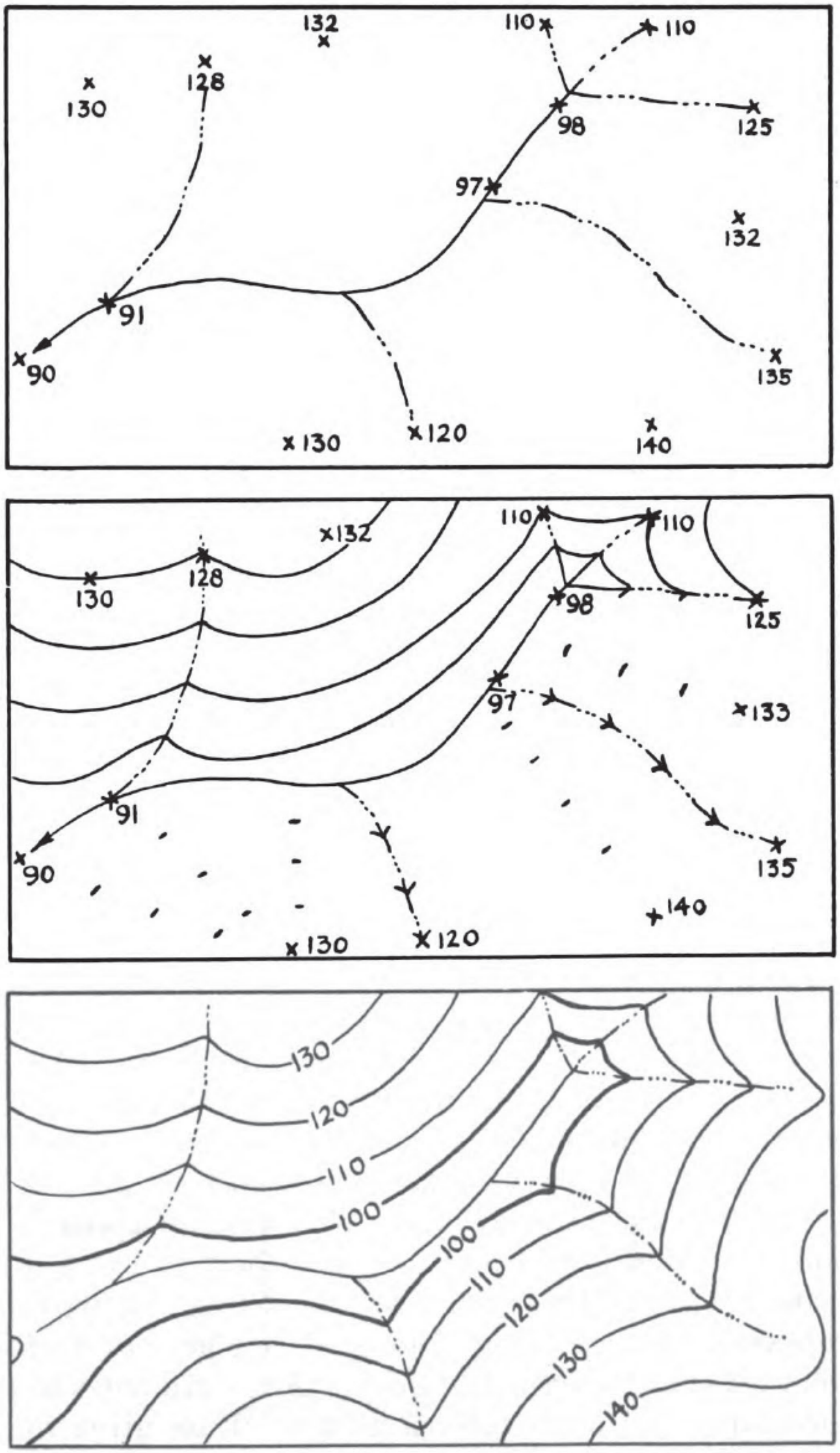


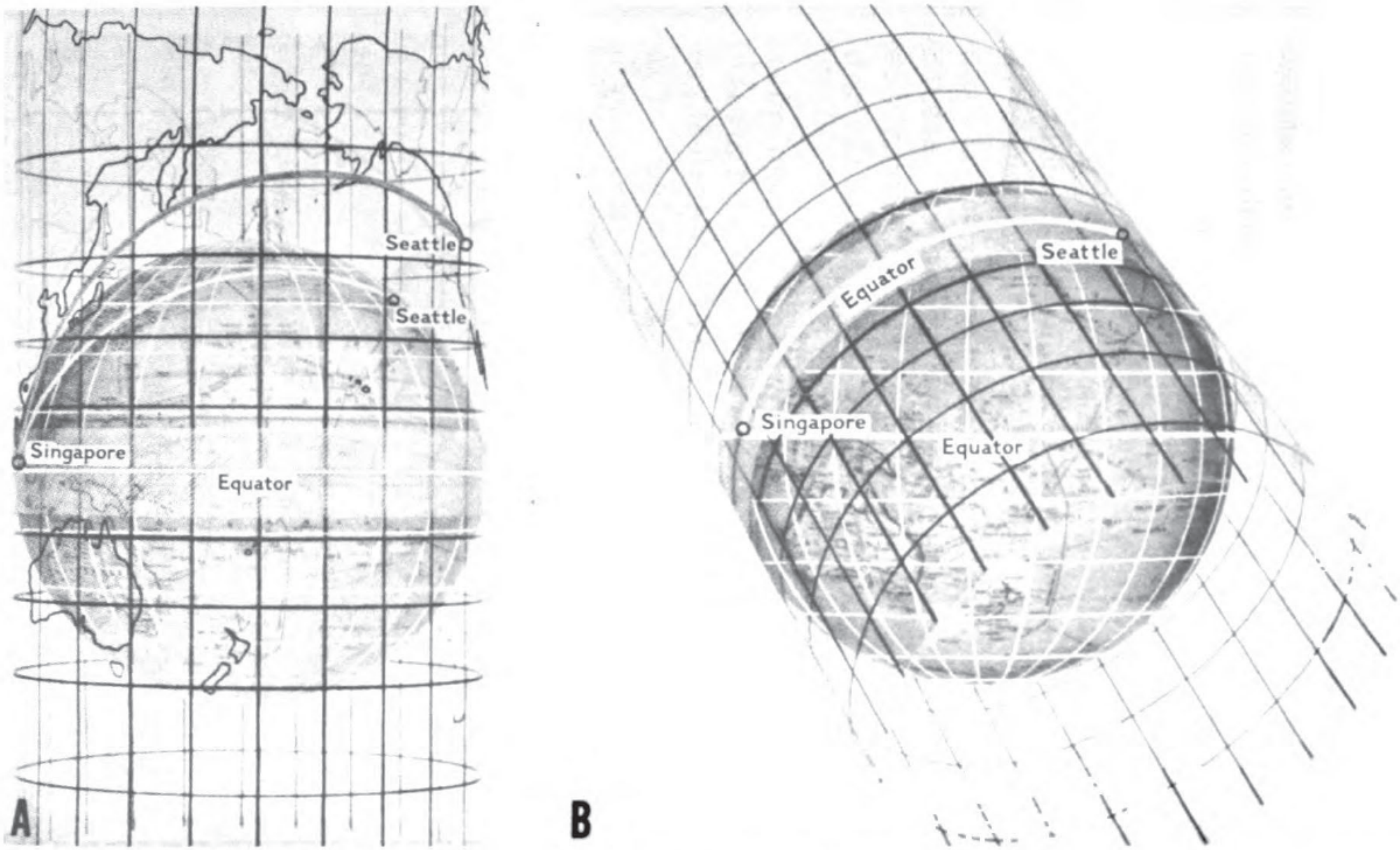
Figure 13–18.—Method of drawing contours by interpolation on drainage net where elevations are given.

and 130 are marked on this stream line by interpolations. V-marks pointing upstream are used to mark such elevations on a stream line. All other stream lines are located in the same manner. Contour locations are marked on the ridge lines in a similar way, except that straight marks normal to the ridge line are used.

MILITARY GRID

The length and direction of a line joining 2 points can be computed from the geographic coordinates of the 2 points, but the computation is long and fairly difficult. In a system of rectangular coordinates, however, if the abscissas (x) and ordinates (y) of two points are known, the determination of the length and direction of the line joining them requires only the solution of a right triangle. In such a system, the position of a point may be determined if the distance of the point from two reference lines intersecting at right angles is known. The two distances which locate the point are measured parallel to the horizontal and vertical axes and are known as the x and y coordinates, respectively. The military grid is a true quadrillage applied upon a projection, uniform in scale and limited in scope by the requirement that it be adaptable to plane trigonometric measurements.

During World War II, the WORLD POLYCONIC GRID SYSTEM, based on the polyconic projection, was used. This was simply an extension of the familiar United States military grid developed by the Corps of Engineers and the Coast and Geodetic Survey in 1918, and it contained the flaws and inherent distortions of the polyconic projection. It has been replaced by the UNIVERSAL GRID SYSTEMS, consisting of the UNIVERSAL TRANSVERSE MERCATOR (UTM) GRID, based on the transverse Mercator projection, and the UNIVERSAL POLAR STEREOGRAPHIC (UPS) GRID, based on the polar stereographic projection. Discussion of these grids, methods of drafting, tables for transformation of geographic coordinates to grid coordinates, and other reference material are given in TM 5–241, *The Universal Grid Systems*, published in 1951 by the Departments of the Army and the Air Force.



From The Round Earth on Flat Paper *by William Chamberlin. Courtesy of the National Geographic Society*

Figure 13–19.—A. The Mercator projection cylinder is tangent upon the earth at the Equator. B. The transverse Mercator cylinder is tangent on some other great circle.

Transverse Mercator Projection

Although the Mercator projection is a mathematical projection, it can be thought of as a cylindrical projection. If you think of it as a cylindrical projection, you can see how the cylinder can be turned so that instead of its being tangent with the earth at the Equator, it is tangent on some other great circle of the earth. (See fig. 13–19.)

However, in the transverse Mercator position, the projection loses the property of straight meridians and parallels, and the loxodrome or rhumb line is no longer a straight line. Since the projection is conformal, the representation of the rhumb line must intersect the meridians on the map at a constant angle, but as the meridians become curved lines, the rhumb line must also become a curved line. The transverse projection, therefore, loses this valuable property of the ordinary Mercator projection.

Also, in the transverse Mercator projection, a hemisphere appears distorted at the outer edges. The 2 shaded areas of figure 13–20 show the varying distortion of 2 equivalent geographic areas on the same projection. The problem of reducing or eliminating this distortion makes it necessary to modify the simple Mercator projection.

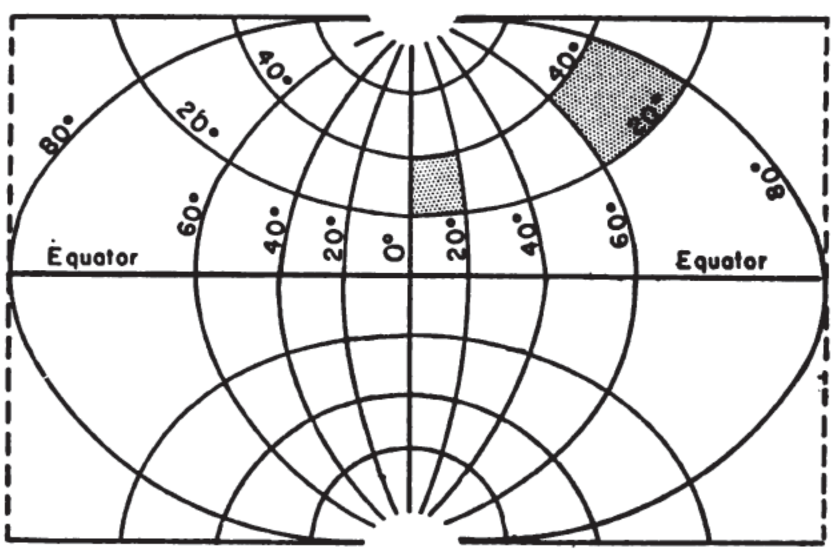


Figure 13–20.—A hemisphere projected on the transverse Mercator appears distorted at the outer edges.

Notice that the 0° meridian in figure 13–21 is tangent to the enveloping cylinder of the projection, and since the radius of the cylinder is equal to the radius of the sphere, there is no distortion along this meridian. Therefore, to reduce distortion, the transverse Mercator projection uses 60 zones, each zone 6° in longitude. For example, a zone centered on 3° is bounded by 0° and 6° of longitude and a zone centered on 9° is bounded by 6° and 12° of longitude, as shown in figure 13–21.

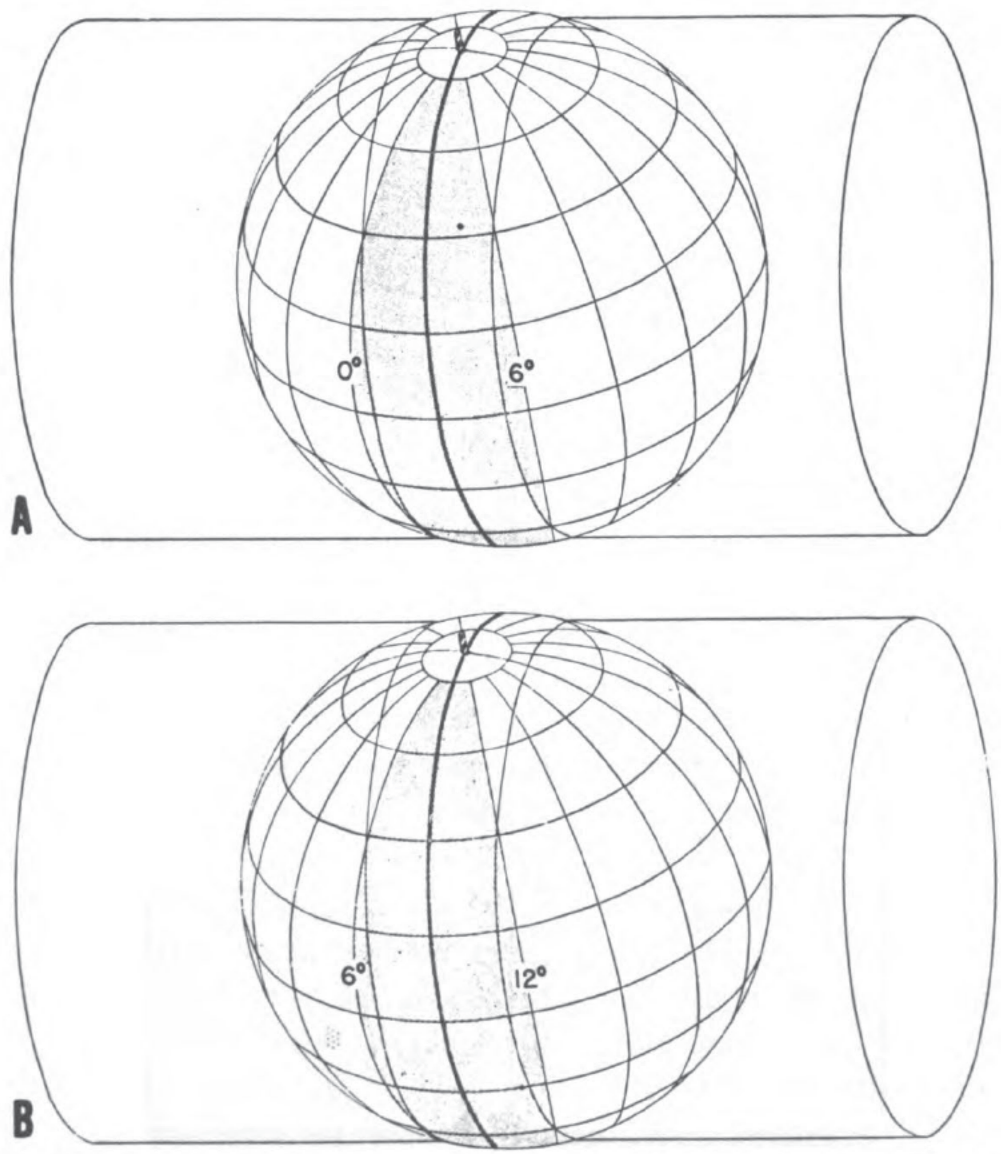


Figure 13–21.—In the transverse Mercator projection, the zones extend 6° in longitude, 3° on one side of a central meridian and 3° on the other.

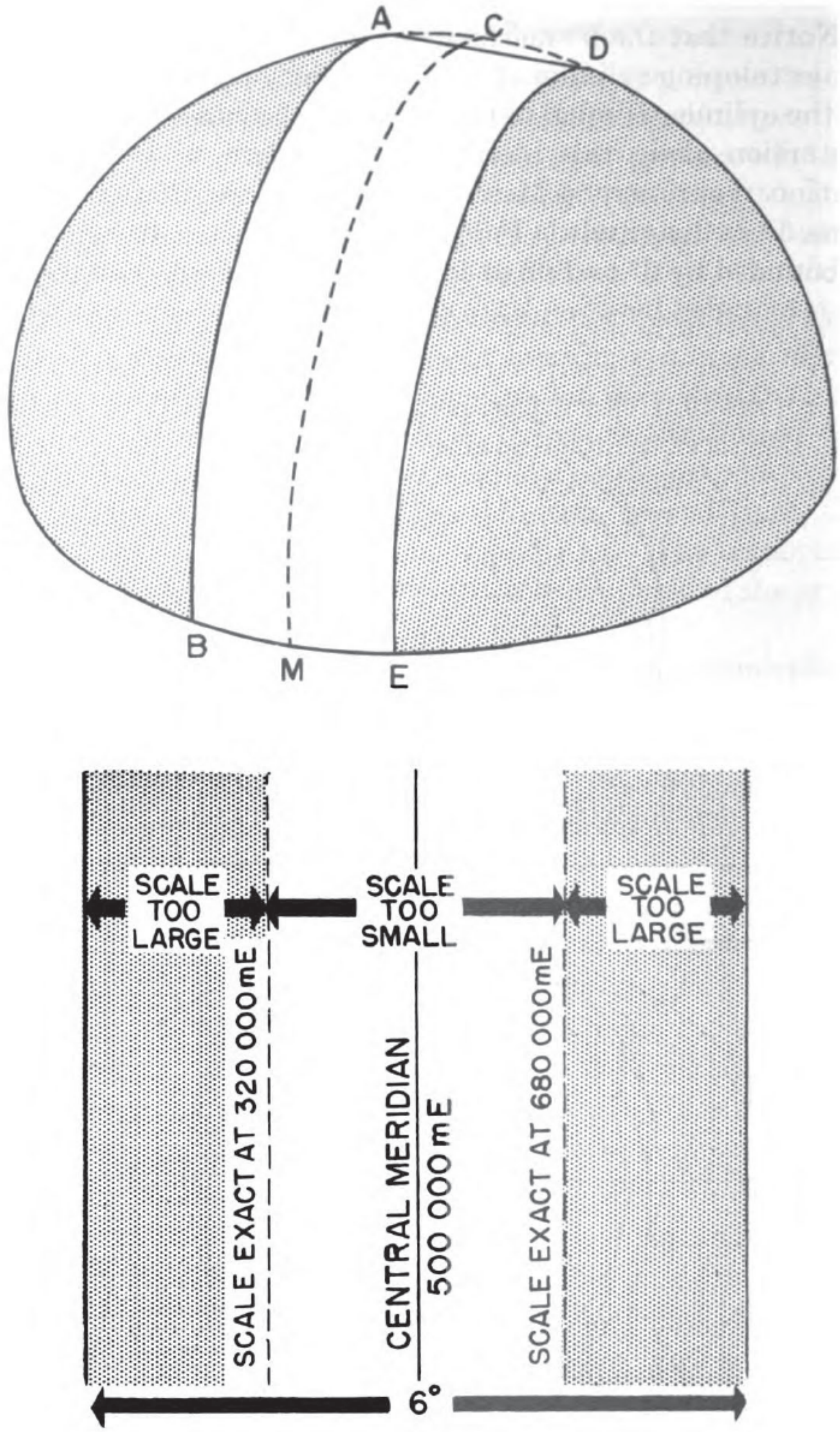


Figure 13–22.—Scale distortion near the Equator in any 6° zone.

Furthermore, for each zone the enveloping cylinder of the projection is moved into a secant position. This causes the radius of the cylinder to become smaller than the radius of the sphere and the cylinder cuts the sphere at two points. Thus two approximately north-south lines become exact distance lines instead of only one. Figure 13–22 illustrates the resulting scale distortion near the Equator in any 6° zone.

As a result, in measuring ground distance to be plotted on map projections, computers must apply scale factors to get the representative projection distance. And in converting grid distances to actual ground distances for precise control of artillery fire, the scale factor may become a quantity to be considered. The ordinary map user, however, need not be concerned with scale factors in giving or using grid references.

Military Grid Reference System

The Military grid reference system is designed for use on maps showing the universal transverse Mercator and the universal polar stereographic grids.

Between the 80° N and 80° S latitudes, the universal transverse Mercator grid is used. The whole area is divided into quadrillaterals 6° east-west by 8° north-south. (See fig. 13–23.) The columns, 6° wide, are identified by UTM grid zone numbers. Starting at the 180° meridian and proceeding eastward, the columns are numbered 1 through 60. The rows, 8° high, are identified by letters. Starting at 80° south and proceeding northward to 80° north, the rows are lettered consecutively C through X (with letters I and O omitted). The designation, called GRID ZONE DESIGNATION, of any 6° east-west by 8° north-south rectangle is determined by reading RIGHT-UP. The column designation, such as 3, is read first. The row designation, such as P, is read after the number.

Each 6° by 8° quadrilateral is divided into 100,000 meter

squares. Columns of squares are identified by letters. Rows of squares are also identified by letters. (See fig. 13–24.) Starting at the 180° meridian and proceeding eastward along the Equator for 18°, the 100,000 meter columns (including partial columns along grid junctions) are consecutively lettered A through Z (I and O omitted). The partial alphabet repeats at 18° intervals. The 100,000 meter rows are lettered

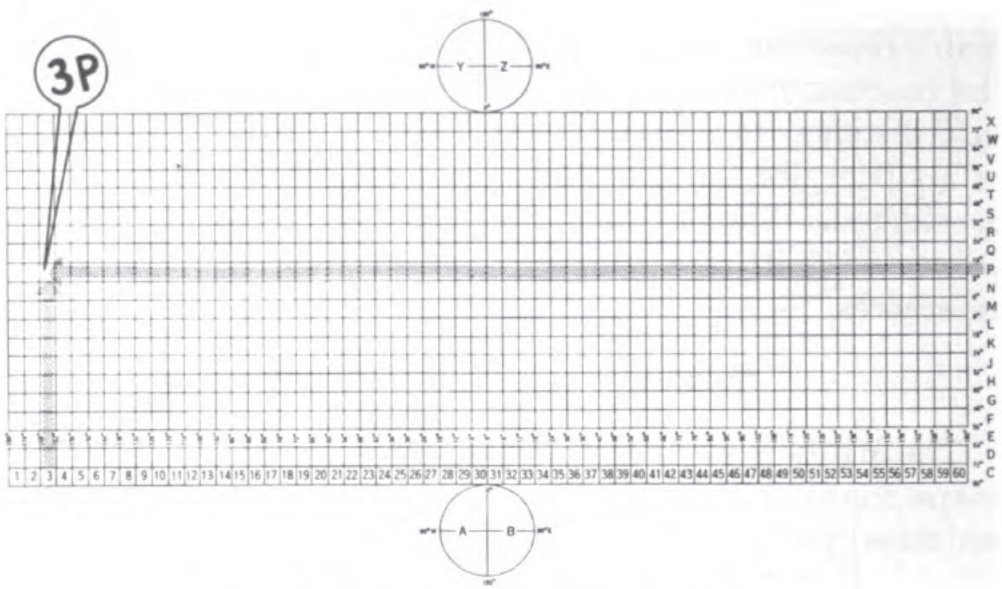


Figure 13–23.—Globe divided into quadrilaterals.

A through V (I and O omitted) reading from south to north. North of the Equator, lettering of rows starts with A at the Equator in the odd numbered UTM zones, and with F at the Equator in the even numbered zones, as shown in figure 13–25. The resultant staggering lengthens the distance between 100,000 meter squares of the same lettered identification. South of the Equator, the 100,000 meter letters also read from south to north complementing the letters above in any one particular zone. The identification of a 100,000 meter square is determined by reading, right-up, first the column letter, as W, and second the row letters, as N. Thus the reference 3PWN of figure 13–24 identifies a particular 100,000 meter square on the UTM grid.

A grid reference consists of a group of letters and num-

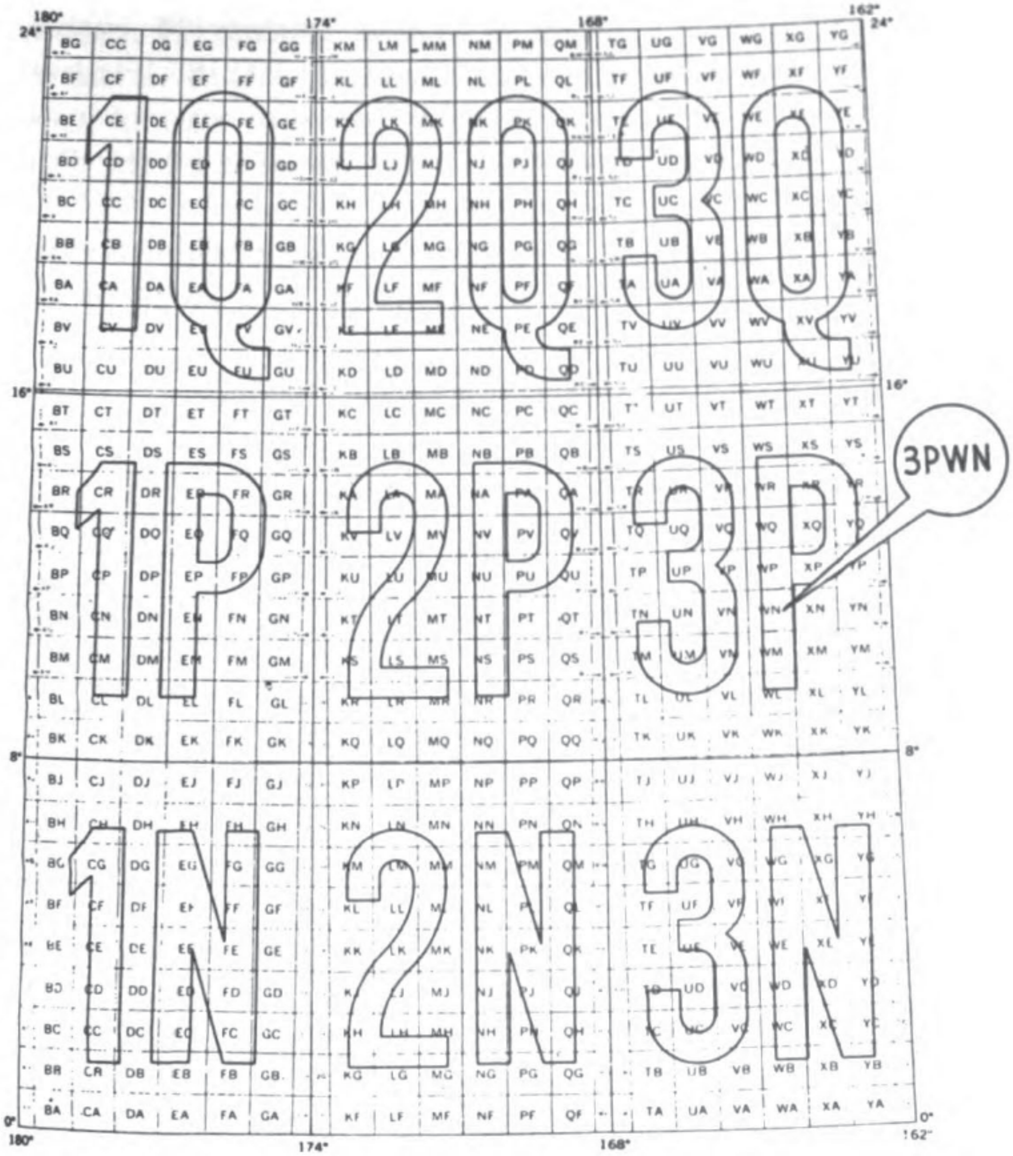


Figure 13–24.—Identification of a 100,000 meter square.

bers which indicate the grid zone designation, the 100,000 meter square identification, and the rectangular coordinates of the point to the desired accuracy. A reference is written as a continuous series of numbers and letters without spaces, parentheses, dashes, or decimal points. For example, (1) 3PWN locates a point within a 100,000 meter square. (2) 3PWN55 locates a point within a 10,000 meter square. (3) 3PWN5354 locates a point within 1,000 meters. (4) 3PWN539544 locates a point within 100 meters.

(5) 3PWN53925443 locates a point within 10 meters.
(6) 3PWN5392454432 locates a point within 1 meter.

Normally all elements of a grid reference are not used. Those omitted depend upon the size of the area of activities and upon interval of the grid lines.

In polar areas, the universal polar stereographic grid is used. The polar areas are divided into two parts by the

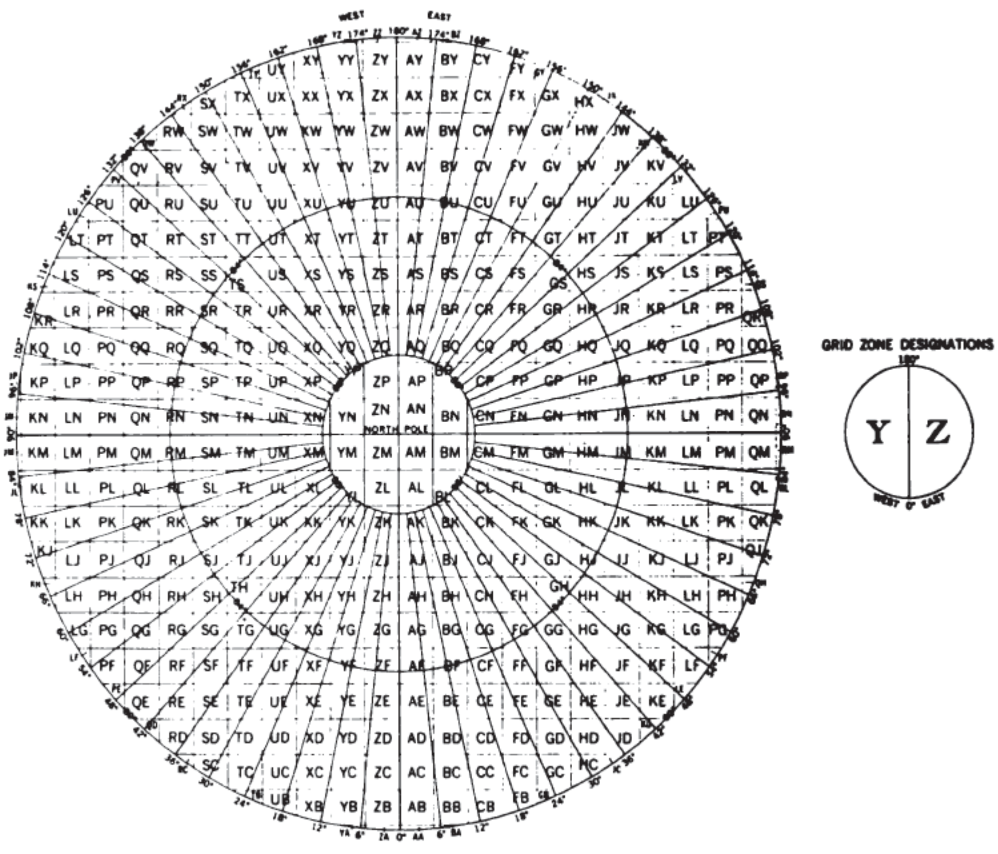


Figure 13–25.—North polar identification of 100,000 meter squares.

180° and 0° meridians. The west half of the north polar area is identified as grid zone Y and the east half as Z. (See fig. 13–25.) The west half of the south polar area is identified as A and the east half as B. (See fig. 13–26.)

In the half of the north polar area identified by the grid zone designation Y, the 100,000 meter columns at right angles to the 90° meridian are labeled J through Z consecutively from left to right. In the half identified by the grid zone designation Z, the 100,000 meter columns are labeled A

through R consecutively from left to right. In both cases, the letters I and O are omitted. To avoid duplicating the 100,000 meter squares in adjoining UTM zones, the letters D, E, M, N, V, and W are also omitted. Starting at the 80° parallel and reading toward grid north, the 100,000 meter rows at right angles to the 180°—0° meridians are con-

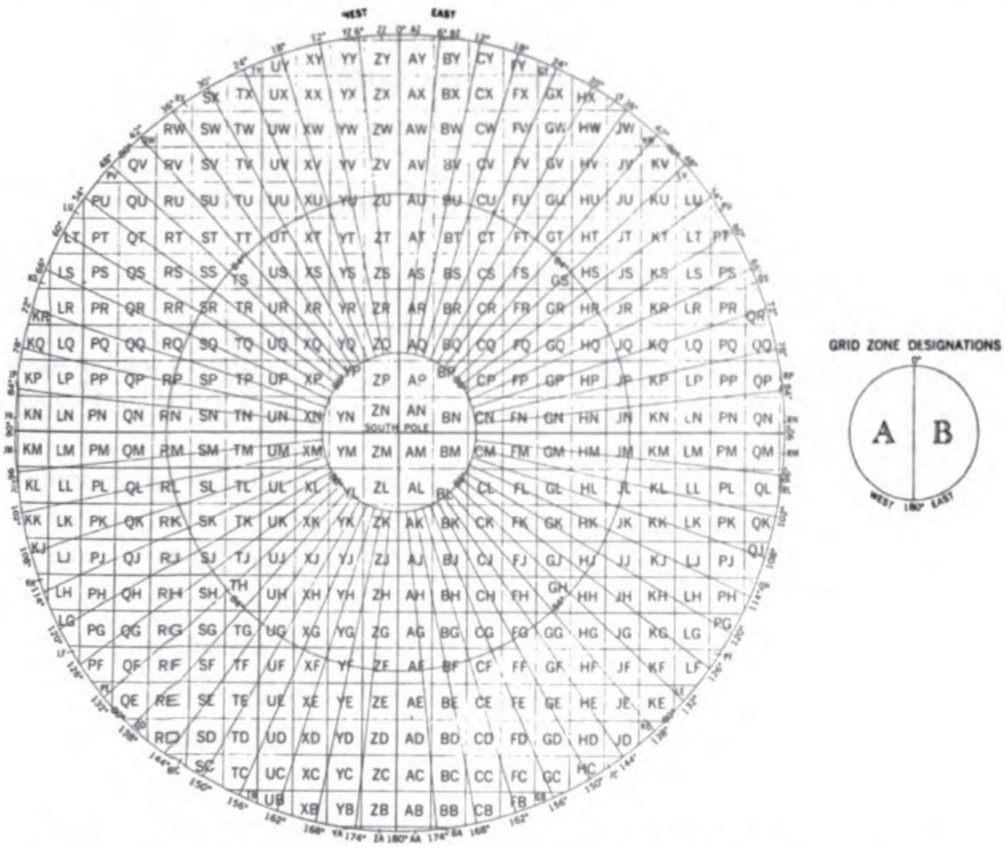


Figure 13–26.—South polar identification of 100,000 meter squares.

secutively labeled A through Z (I and O omitted). The north polar identification of a 100,000 meter square consists of two letters. It is determined by reading, right-up, first its column letter, second its row letter. For example, the pairs of letters AM, AN, ZM, and ZN identify the four 100,000 meter squares adjacent to one another at the North Pole. In the south polar area, the identification of the 100,000 meter squares follows a plan similar to that used in the north polar area, as illustrated in figure 13–26.

QUIZ

1. What surface on the earth has been generally adopted as the reference plane for zero altitude?
2. What meridian is usually taken as the prime meridian?
3. What parallel is used as the reference parallel?
4. What are the units of measurement used in the sexagesimal system of measuring parallels of latitude and meridians of longitude?
5. What is the ellipsoid whose measurements are generally used by the Navy for the measurements of the earth?
6. What international measurement was adopted in July 1954 for use by the Defense Department?
7. What are the four map projections which have wide use in the Navy?
8. Name five advantages of the Mercator projection.
9. Since the distance between meridians is kept constant on the Mercator projection, what must be done with the distances between parallels in order that the distances on a map remain proportionately the same?
10. What does a straight line between any two points on a gnomonic chart represent?
11. Name four advantages of the Lambert conformal conic projection.
12. In the polyconic projection, how is the earth considered?
13. What are four advantages of the polyconic projection?
14. What are the two types of borders used on H. O. nautical charts?
15. In general, when are plan borders used?
16. What does reproducing a chart at 1 to 1 scale mean?
17. What is a sounding on a chart?
18. What fathom curves are usually selected for plotting?
19. How do bathymetric curves differ from fathom curves?
20. From the point of view of the draftsman, what are the disadvantages of the hachure method of showing relief?
21. Why is the method of contour lines the most accurate means of depicting relief?
22. Describe an index line.
23. Name two disadvantages of the contour-line method.
24. On what two map projections are the universal grid systems based?

CHAPTER 14

LITHOGRAPHIC DRAFTING

PRINTING METHODS

Charts may be duplicated by either photography or printing. Printing is generally used because by its use large quantities of single- or multi-colored charts can be turned out at comparatively high speeds. Any of several printing methods may be used.

Some of the earliest charts were reproduced from engraved or etched-out copper plates. The image was engraved or etched into the surface of a smooth copper plate and the etched-out areas were filled with ink. The operator then wiped clean the surface of the plate, leaving the ink in the sunken areas only. After this, he placed a sheet of paper over the plate and applied pressure. The paper absorbed the ink from the sunken areas to produce the image. This process is known as INTAGLIO PRINTING. It is used today for printing postage stamps and paper money. In the Hydrographic Office, existing copper plates are still used to provide proofs or master copies for other methods of printing.

The exact opposite of the intaglio process is LETTERPRESS PRINTING. This process involves the use of raised letters and lines. These raised areas are inked and pressed against a piece of paper to make the impression. Since the low areas are not inked in the process, they do not print, but show up as white space on the paper.

There is still a third type of printing, known as LITHOGRAPHY. It is the process that is generally used for printing charts. It is chosen because of its economy, versatility, and simplicity. In this process, the printing areas are neither raised nor etched out. Instead, these areas are the same

height as the blank, nonprinting areas around them. However, the nonprinting areas are chemically treated so that they will receive water and repel ink. The printing areas, on the other hand, are covered with a greasy surface which will take the ink, but not the water. Therefore, only the image areas ink up and print.

In the beginning, lithographic prints were pulled directly from drawings made on a slab of limestone, but today thin zinc or aluminum plates have replaced the limestone, and the printing is no longer done directly from the image. Instead, the inked image on the plate is first printed on a rubber blanket. The blanket, in turn, yields or "offsets" the image to the paper. As a result, the process has come to be known as *offset lithography* or *offset printing.* This is the process with which you are concerned as a lithographic draftsman.

HOW CHARTS ARE MADE

The first step in reproducing a chart is the gathering or compiling of the information that is to go in it. Various charts and topographic maps are used for this purpose, as well as documents, sailing directions, and reports of hydrographic surveys. Once this information has been compiled, it is turned over to the topographic draftsman who works it up into an original black-and-white outline drawing.

The original drawing is then photographed with a special copying camera, known as a process camera. The cameraman may use film in the camera, if the job is "rush and if a fine degree of accuracy is not required. However, film has a tendency to stretch or shrink with changes in temperature and humidity. When very accurate work is necessary, sensitized glass plates are better for chart purposes, because glass is comparatively stable.

Glass plates fall into two categories, dry plates and wet plates. A dry plate is similar to film. It is simply a piece of glass coated with a light-sensitive emulsion. These plates are coated by the manufacturer and come in packages ready

for use. Wet plates are more involved. When the cameraman is using a wet plate, he must coat the glass himself, and he must then make the exposure while the glass is still wet. Although wet plates are more difficult to handle, they reproduce fine detail better than dry plates or film. They are also easier to correct. Only limited corrections may be made on film.

In the camera room, the cameraman mounts the original drawing on a copy board in front of the camera. He then opens the lens shutter, turns on the lights, and focuses the image on a sheet of ground glass at the back of the camera. By moving the copy board and the front of the camera in or out, he can regulate the size of the image on the ground glass. That is, he can enlarge it, reduce it, or make it the same size as the original drawing. To produce an image of the exact size required, he often uses a strip of paper on which has been marked two lines indicating the distance between two predetermined points on the original. When the lines on the measuring strip coincide with the selected points on the image on the ground glass, and the image is sharp, the desired size has been obtained. (See fig. 14–1.)

He then closes the shutter of the camera, coats the plate with the proper chemicals, removes the ground glass, and slips the wet plate in its place. Next, he opens the shutter again and turns on the lights to make the exposure. After the required time, he closes the shutter and turns off the lights to bring the exposure to an end.

During the exposure, the light is reflected from the copy through the lens and onto the sensitized plate at the back of the camera. The sensitive coating on the plate is affected in proportion to the amount of light striking it. When the plate is removed from the camera and developed and fixed in proper chemicals, the areas that were struck by strong light reflections turn black, and the other areas dissolve, leaving transparent, open areas on the glass.

The developed plate is called a negative, because the light has registered on it in reverse. The plate is now black where

Figure 14–1A.—Steps involved in the lithographic printing process.

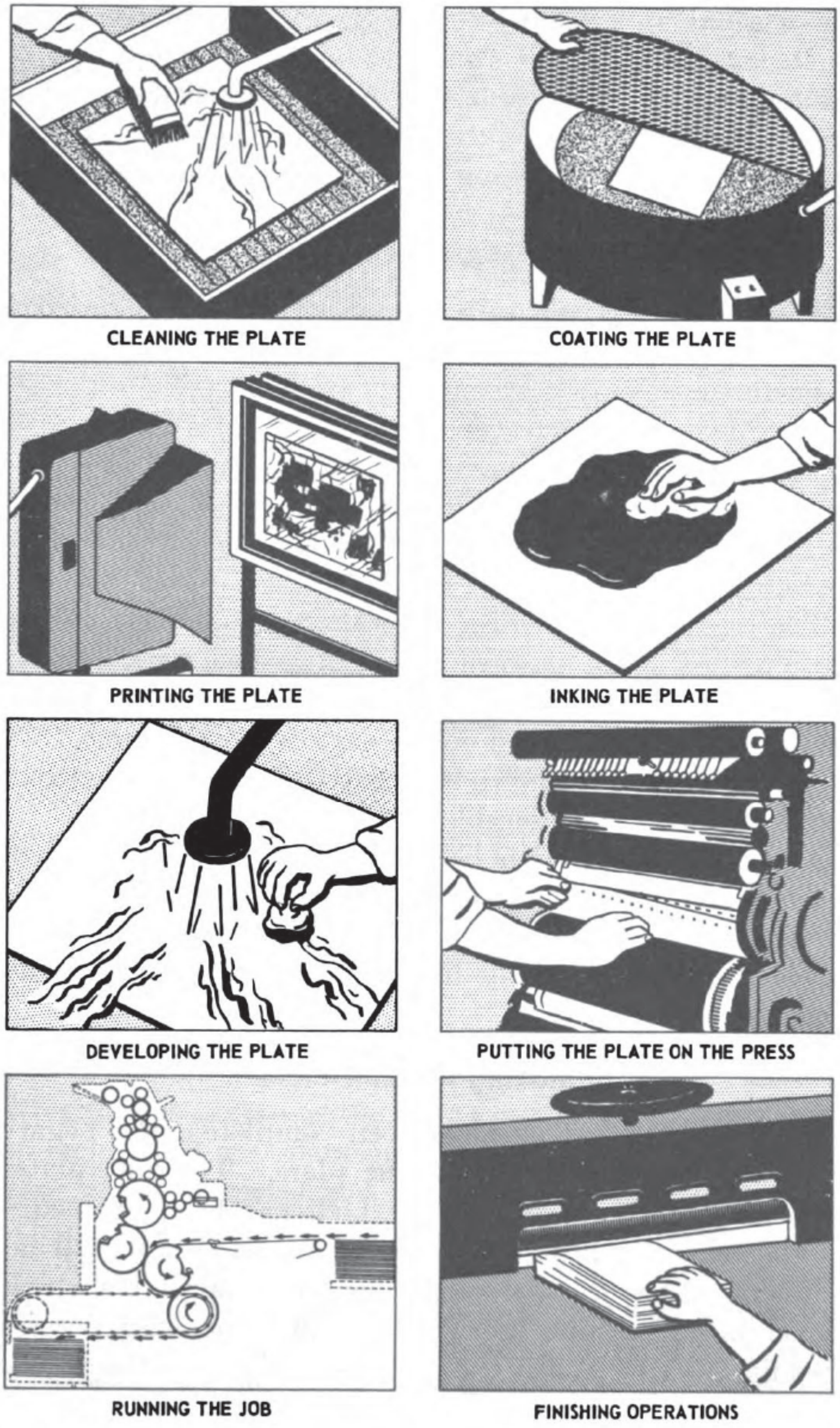


Figure 14–1B.—Steps involved in the lithographic printing process—Continued.

the original copy was white and transparent in areas where black lettering or lines appeared on the original copy. A positive print can be made by exposing sensitized photographic papers to the light through this negative. Positive photographic prints are used for checking purposes and as color guides.

Retouching the Negative

The negative is generally retouched before it is used for making photoprints. Retouching must be done to remove imperfections, such as transparent pinhole spots, in the dark areas. These imperfections may have been caused by smudges on the original art, dust on the plate or lens, or by chemical action in the development process. They must be painted out with a brush dipped in a mixture of lampblack, asphaltum, and turpentine. (See fig. 14–2.)

The transparent areas of the negative also need some attention. Filled-in or weak places in lines, letters, and symbols must be recut with a lithographic needle. New data may also be hand-lettered on the negative at this time. This recutting process is known as negative cutting or engraving, and it demands considerable experience and skill.

After the negative has been retouched, paper photoprints are made and sent to the proper section for analysis. If revisions or corrections are required, they are made by hand on the negative before the lithographic zinc plate is printed from the negative.

Making the Zinc Plate

After all corrections have been completed, the negative may then be printed on the zinc plate. The zinc plate is simply a thin sheet of metal which has been grained, or roughened by grinding with abrasives, so that it will hold moisture. After the plate is grained, it is placed in a whirler, a machine which spins it or rotates it in a clockwise direction. (See fig. 14–1.) While the plate is spinning in the whirler, the platemaker pours a light-sensitive solution consisting of egg albumin and ammonium dichromate over it. The whirl-

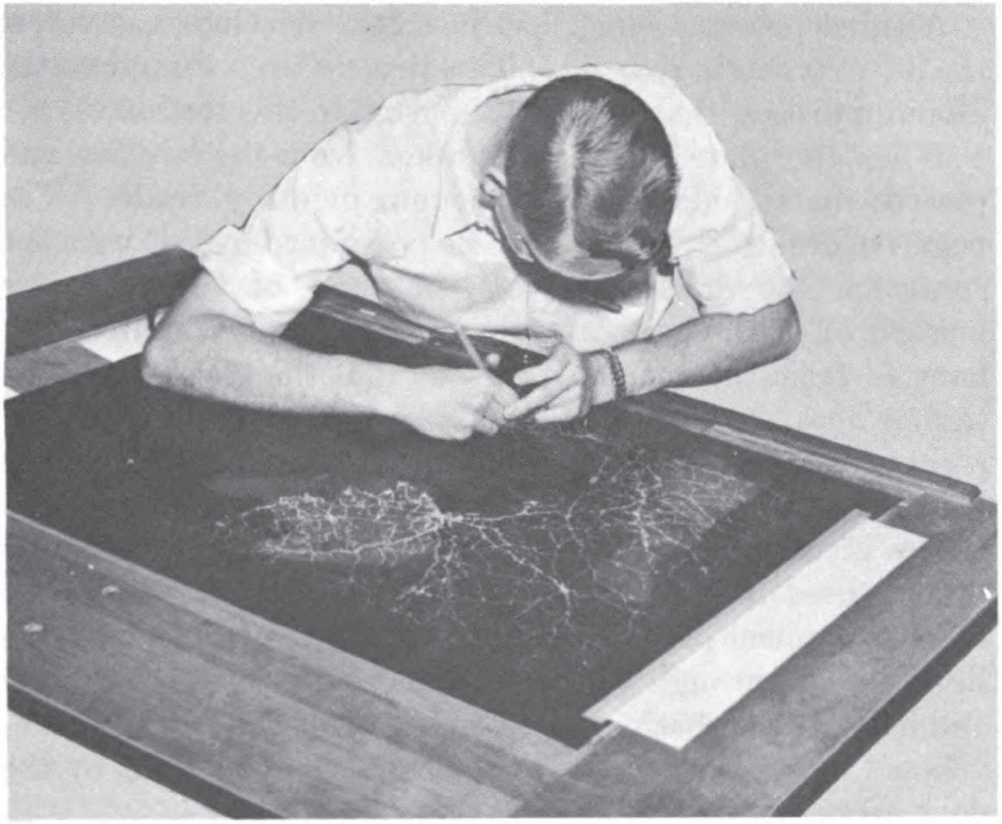


Figure 14–2.—Retouching a film negative.

ing action causes the coating to spread evenly over the plate and also causes it to dry quickly. As the plate begins to dry, the coating becomes light-sensitive, like the emulsion on photographic paper. It must be handled in subdued light from then on.

The ALBUMIN COATING is used for the ordinary run of work. There is another process which requires a different kind of coating. It is known as the DEEP-ETCH process. In making deep-etch plates, the operator etches the image slightly below the surface of the metal, and this, of course, makes corrections or changes on the plate difficult. Deep-etch plates have a much longer life than albumin plates, but since charts are seldom printed in large quantities, the lasting qualities of the plate are not so important as the simplicity of the process and the way the plate lends itself to corrections. Therefore, the deep-etch process is rarely used in the printing of maps and charts.

A third process, which has just been developed, involves the use of a casein coating. This process is so similar to the albumin process that it is not discussed in this section.

When the plate is dry, it is taken from the whirler and placed, coated side up, in a vacuum printing frame. The negative or negatives may then be positioned over it with the emulsion side down. All unused parts of the plate are masked off with sheets of goldenrod paper. The air is exhausted from the vacuum frame so that the plate is pressed tightly against the negative. The frame is raised to an upright position before an arc lamp and the exposure is made for the correct length of time.

The printing, or exposure, of the plate is similar to the process used in making prints on photographic paper, but the development process is rather different. In this case, the light passes through the transparent areas of the negative and hardens the coating on the plate, while the coating is unaffected in areas where it is protected from the light by the dark areas of the negative.

After exposure, the plate is removed from the vacuum frame and placed on a table. There, it is covered with lacquer, followed by a thin, uniform coating of developing ink. Next, it is placed in a sink and developed in running water. After about 60 seconds in the water, the coating dissolves in the areas that have not been hardened by the light, and the lacquer and ink are carried away in these areas along with the albumin coating so that the bare metal of the plate is left exposed. The light-hardened areas of the coating do not dissolve, and these inked-over areas remain on the plate as the image.

The plate is then etched with a solution which makes the open, nonprinting areas insensitive to grease. The platemaker may also strengthen the image by going over it with an additional coating of ink. First, he moistens the plate so that ink will not adhere to any but the image areas. Then he inks it with a hand roller. This strengthening operation is known as ROLLING UP the plate. After the plate is rolled up,

it is fanned dry. If minor alterations or additions are necessary when the plate is inspected, they are made directly on the plate by the lithographic draftsman.

Finally, since some developing inks dry quickly, and once dry, will no longer take offset printing ink, the platemaker washes the developing ink from the image with turpentine and then rubs a mixture of asphaltum into the image areas. Asphaltum forms a grease base which never dries, and the plate may be stored indefinitely.

When the plates for all the colors on the chart have been made, composite color proofs are printed. This is a trial printing of a few copies of the chart in its final assembly or production form. These lithographic proofs are thoroughly inspected by the cartographic, editing, and lithographic staffs. Revisions are noted on the proof copies, and then any plates which require revisions may be corrected by the lithographic draftsman. If it seems more expedient, however, either the film negatives or the original art may be corrected instead, and in that case, the plate is remade.

Offset Press

The plate is now ready for the press. The offset press consists of an automatic feeder, a printing unit, and a delivery unit. The printing unit consists of an ink fountain and rollers, a water fountain and rollers, and three large metal cylinders. The plate is attached to one of these cylinders, a rubber blanket is attached to another, and the third carries the paper through the press, forcing it against the rubber blanket to make the printed impression.

The paper is stacked on a feed table that automatically rises as the sheets are fed into the press. When the press is turned on, jets of air shoot out of pipes and float the top sheets in the paper stack. A set of suction cups, or sucker feet, then swing down against the edge of the top sheet and pull it to a position where it is caught by two rubber-rimmed rollers which force it onto a set of moving conveyor tapes. These tapes carry it down the feedboard to the printing unit.

At the end of the feedboard, it reaches a set of guides which position, or register it, and stop it momentarily before it is carried into the printing unit. A second later, the guides rise and a set of curved grippers close on the edge of the sheet and pull it around the impression cylinder.

As the cylinders revolve, the plate passes under the dampening rollers and then under the inking rollers. The dampening rollers keep the nonprinting areas of the plate wet so that they will not take ink when the plate passes under the ink rollers. As a result, only the image is inked. After the plate passes under the ink rollers, it contacts the blanket cylinder, transferring the inked image to the blanket. The blanket, in turn, offsets the image to the paper, which is forced against it by the impression cylinder.

At the end of this printing cycle, the impression cylinder grippers release the sheet to another set of grippers which carry it to the delivery unit. Here it is deposited on a stack of printed sheets. After the run is completed, the plate is taken from the press, washed out with turpentine and rubbed up with asphaltum. It is then stored for future use.

FINISHING ORIGINAL ZINC PLATES

Since many charts are larger than the size of a single negative, it is frequently necessary for the cameraman to photograph the left side of the chart on one negative and the right side on another. The platemaker then prints these negatives one at a time on the plate. He prints the left side first, masking off the unused portions of the plate on the right side with goldenrod paper. He then reverses this process, masking off the left side and printing the right. He uses match marks prepared on the original drawing to guide him in positioning the negatives so that the two images will be aligned when the plate is printed.

As a rule, it is not a safe policy to butt the two images together nor to allow them to overlap, because the contour and projection lines may not exactly match. Therefore, the platemaker leaves a slight gap between the two images when

Figure 14–3.—Joining features on a two-negative plate.

he prints the plate. He usually separates or breaks the images at the line of least resistance. The break may come at a projection line or it may swing down in an arc, so as to require the least amount of handwork. The plate is then sent to the lithographic draftsman for finishing. He must correct the broken areas of the border and scale, broken projection lines, and contours. (See fig. 14–3.)

In completing the broken lines on a two-negative job, you will work much the same as a topographic draftsman, except that you will use special inks and work on the grained zinc plate instead of paper, plastic, or coated zinc. Ruling pens are required for projection lines and borders, but broken contours and shorelines are replaced freehand with a fine pen.

After you have finished connecting the contour lines, pro-

jection lines, and so on, you should take a piece of chalk and encircle the areas where you have done the handwork. (See fig. 14–3.) This will call these areas to the attention of the men in the transfer room, who must process these areas to secure a printing image consistent with the rest of the plate.

TINT PLATES

Color adds to the scope of charts. It makes them easier to read and renders certain features conspicuous. You can more readily distinguish between adjoining areas when they are printed in different colors. Color also lends emphasis to important features and areas such as dangerous shoals, depths of 3 fathoms or less, channels, lights, and beacons. Contrasting colors, thus, can be as valuable in clarifying a chart as identifying names and descriptive legends.

But color also involves additional work. To begin with, you must have a separate plate for each color to be run. Each of these plates must then be run on the press in a separate color of ink. This often involves running the job through the press 3, 4, or even more times. Besides the black plate, hydrographic charts generally require gray, blue, and magenta plates, and other colors are sometimes used as well.

Plates that are to print in gray or blue are generally referred to as **TINT PLATES**. The black plate is generally called the **BASE PLATE**. The other plates carry the name of the color they represent, as the **MAGENTA PLATE** or the **GREEN PLATE**.

The draftsman prepares an original black-and-white line drawing for the base plate. He could also prepare a separate black-and-white drawing of the area that is to be printed in each particular color. Each of these drawings would be photographed and the resulting negative used in producing a zinc plate. This is the usual method, as a matter of fact, for color-separating the line work of a chart, but the originals for the tint plates which print the flat colors are usually drawn either directly on the lithographic zinc plate or as a negative on translucent (or transparent) plastic. This serves to eliminate unnecessary processing and material.

Another method is sometimes used in obtaining color plates for line drawings and illustrations. The artist prepares an original, composite drawing in black and white and then has as many negatives shot from it as there are colors to be printed. The negatives are masked off; that is, parts are painted out, so that each negative carries only those portions of the design that are to go in a single color. The masked negatives are then printed on separate zinc plates and each of the plates is run on the press in the proper color of ink. This method is very accurate, but because of the many crossing lines and small features on a chart, considerable negative engraving is required. Therefore, although it works very well for illustrations, it requires too much time for chart work.

Blueline Plates

There is still a third method, known as the blueprint or BLUELINE METHOD. It is the one generally used in producing charts. This method consists of making a blueprint image on the plates themselves and then filling in the proper areas on each plate with a greasy ink.

To do this, the platemaker coats each plate with a light-sensitive blueprint solution and then prints it with the same negative that he used in making the base plate. When the plate is developed, it carries a weak blue, positive image that is identical with the image on the base plate. However, the lines of the blueprint image will not take ink when the plate is put on the press. Therefore, it is your job as a DML to trace over the lines or fill in with greasy ink the parts that you want to print. A separate blueline plate is made for each color that is to be printed, and on each plate only those areas that are to print in a particular color are inked. Since all plates are made from the same master negative, perfect color registration can be achieved by this process.

Methods of working on blueline plates and the materials used are discussed in detail in *Draftsman 3*, NavPers 10471. Therefore, in this chapter, only the working methods and ma-

terials used in the gum arabic process, which is mentioned briefly in *Draftsman 3*, and the method of shading the six-fathom line are described.

Gum Arabic Process

The gum arabic process was used for preparing blueline tint plates back in the days before lithokote was perfected. Instead of painting in the image areas with tusche or lithokote, the draftsman painted over the nonprinting areas of the plate with a solution of gum arabic. The gum arabic made these areas insensitive to grease. The plate was then sent to the transfer room where the image areas were covered with asphaltum so that they would take ink when the plate was put on the press.

Today, the gum arabic process is used at times when a dot pattern is to be transferred to certain areas of the plate. You can mask off the adjoining areas by painting them out with gum arabic. It is a good idea to add brown or blue coloring to the solution so that you can see your outline. After the areas have been masked off, the plate is sent to the transfer room. There the transferrer will apply the dots with a transfer sheet.

Shading

As you know, the water areas out to the three-fathom line are generally shown as solid blue tint. In addition, a blue line is sometimes used to indicate the limits of the six-fathom area. This is an aid to ships which have a greater draft than six fathoms. The six-fathom line is generally indicated by a ribbon of blue.

Until recently it was the practice to shade the ribbon line so that the outside was darker than the inside edge. However, shading is a delicate operation. If it is not done properly, the entire area may fill in when the plate is put on the press.

If you are called on to shade an area on a tint plate, you must work with a tusche crayon. Tusche crayons are similar

to those used in making liquid tusche. They come in different degrees of hardness and are applied directly to the plate. Areas covered by the tusche crayon have a pebbled, rather than a solid finish, and will therefore print as a tone rather than as a solid color.

If you use a soft crayon and a good deal of pressure, the resulting tone will be rather dark, but if you use a hard crayon and little pressure, the tone will be light. By varying the pressure and the type of stick used, you can vary the tone and thus produce gradations of color shading from dark to light.

To draw a shaded ribbon on the water plate, you should first tusche in your outline by following and connecting, with pen and tusche, the dotted lines representing the limits of the 6-fathom depths. Then take your tusche crayon and run a broad stroke along the inside of your outline. This shaded stroke should come close to, but not touch, your contour line. Next, apply liquid tusche with pen or brush from the middle of your crayon stroke to the middle of the contour line. Half of your pebbled crayon line will then be tusched solid, and it will print as solid blue. The other half will print as a shade of lighter blue.

TINT MASKS

Work for tint plates is generally done on the zinc unless the run is long or the work is extremely detailed so that 35 hours or more are required for doing the job. In this case, a blueline image is printed on a sheet of grained transparent vinyl plastic (or, in some cases, glass) and the nonprinting areas are masked off or painted out by hand. The painted-out plastic is then known as a MASK or TINT NEGATIVE, and the areas which are painted out on it are the reverse of those painted on the zinc. For example, all areas except those to be printed in blue are painted out on the mask for a blue plate. (See fig. 14–4.)

Although such masks require more time than is required to paint the plate, the extra time is justified. The image on

Figure 14–4.—Two or more men may work on the plastic mask or tint negative at the same time.

a lithographic plate may lose its sharpness after several thousand impressions. If larger quantities are needed, a second and, possibly, a third plate may have to be prepared. If a tint mask has been prepared, new plates can be made from it in much less time than it takes to prepare a zinc plate by hand.

In preparing a mask on plastic, you may use a pen and Grumbacker's ink for making the outline. Since ink chips and cracks with age, a drop of glycerin may be added to give it more flexibility. Also it is a good idea to thicken your outline and to fill in large areas with oil opaque.

Bluelines should always be opaqued or painted in on the grained (back) side of the plastic. This is necessary so that the painted areas will be in contact with the zinc when the plate is printed. If the inking were done on the front of the plastic, the thickness of the plastic would allow the light to spread or seep under the inked areas during the exposure.

Use a light table rather than the regular drawing table when you work on tint masks. The light coming through the transparent plastic or glass will indicate whether you have covered an area adequately. Be sure that your overhead light is dim enough so that it will not interfere with the illumination from the table.

For outlining intricate tints, a fine stiff pen such as Hunt 102 or 104 is preferred. Ink the pen lightly to avoid having the ink creep or spread over the line being followed. If you clean the surface of the plastic with an artgum eraser, ink spreading may often be lessened. Avoid using cleaning solutions and opaquing inks that may contain a plastic solvent, as even a small amount can distort the sheet enough to make it useless.

As you draw, thicken the outline to about $\frac{1}{32}$ or $\frac{1}{16}$ of an inch. Take care not to thicken it much above these limits as wider inked areas tend to crack. Using oil opaque, widen the line to $\frac{1}{2}$ inch or more and fill in the areas of moderate size with even brush strokes. The coating is kept even in order to ensure perfect contact with the zinc when the mask is printed on a plate. If it is necessary to touch up areas, you should always do your touch-up work on the opposite (top side) of the mask so that the bottom side will not be lumpy or uneven.

If errors occur, you can scrape the ink from the plastic with a razor blade. It may then be necessary for you to retrace the blue lines.

When you outline on glass, use a fine brush and an opaque paint with an oil base. For filling in broad areas, use oil opaque, a preparation consisting of asphaltum, lampblack, and turpentine. Apply it with a chisel-edge brush.

You can reduce the amount of opaquing on plastic by covering areas with goldenrod paper. When you use the goldenrod, you must first outline the area and then thicken the outline until it is at least $\frac{1}{2}$-inch wide. Then, instead of filling in the broad areas with opaque paint, wait until the outline is thoroughly dry and tape a sheet of goldenrod on

the top (nonworking) side with red cellulose tape. Although this paper masks out the light when the plate is printed, it is thin enough for you to see through. You will still be able to see the outlines on the transparency.

Next take a knife or razor blade and cut windows in the goldenrod paper to expose the areas that are to print. To keep from cutting or scratching the surface of the mask, you may insert an extra sheet of transparent plastic between it and the goldenrod. Cut within the painted outline, but be sure that the goldenrod overlaps the painted lines by at least ¼ of an inch. Some operations allow the goldenrod to extend to within approximately ⅛ of an inch of the image areas. This is done so that, if the ink chips or cracks in the future, less touch-up will be necessary.

The irregular edges of the masking paper should be taped enough so that the mask can be handled without its coming loose, but don't apply so much tape that the goldenrod can't be loosened easily. The platemaker may have to loosen it to restore its flatness.

After the plate is printed, the tint negative is stored for future use. It can then be taken from the file and corrected as changes in the information on it occur.

CHALK POWDER OFFSET PLATES

If the original negative is lost or damaged, a different method, known as the CHALK OFFSET PROCESS, may be used. The base plate is delivered to the transfer room where it is rolled up with black ink. A piece of clean chart paper is then positioned over it and taped down. It is then run through a pressure press. The pressure causes the inked image to be transferred to the chart paper. The chart paper is next dipped in a trough containing brown chalk. The chalk sticks to the wet image, but can be shaken off the smooth surface of the paper. The paper is then taped down against the grained surface of a zinc plate, and the two are run through the pressure press again. This time, the pressure causes the chalked image to transfer to the metal plate.

The chalk offset process plate is delivered to the lithographic drafting section where it is used in making a tint plate by a method similar to that used in preparing blueline tint plates. You must be more careful when working with a chalk plate, however, as the chalk image is more easily smeared than the blueline image.

Offset impressions of simple designs are usually sufficiently distinct to serve as guides for the artist or draftsman. If the design is quite intricate, however, the finer details on the chalk offset plate may not be clear. Since chart paper shrinks or swells with changes in humidity, chalk offset plates are also subject to distortion, particularly when the design covers a large area. This can result in imperfect register of colors in the final printing. If there is no way to control the humidity, it is sometimes necessary to wait for a day or two until the weather conditions are right before an accurate plate can be made.

MAGENTA PLATES

The compass rose and certain other information are generally run on a separate plate which is printed in magenta. This information is placed on a separate plate because it must be changed frequently. Magenta ink is used because it contrasts well with the other colors on the chart. It is used extensively on fluorescent base aviation charts because it stands out well under fluorescent lights. The color was chosen by the International Hydrographic Office.

Magneta-plate information may be prepared as an original black-and-white drawing by the drafting section or it may be prepared on plastic by the lithographic draftsman. The lithographic draftsman may place the information on the plastic sheet in the position in which it will appear on the plate or he may condense the information. That is, although he draws each feature to its full size, he places them closer together than they will appear on the plate. He may even include the information for several magenta plates on one plastic sheet. Since a film negative will be made from

this sheet, this serves to save film. The film is later cut apart and assembled on a transparent plastic sheet so that the features are in their proper position.

A typical magenta plate may include several compass roses, a dozen or so symbols, and several notes and notations. The first step in preparing such a plate by negative assembly consists of assembling complete positives of the compass roses. At the Hydrographic Office, these roses are printed in standard sizes on a thin transparent base. In order to assemble such a rose for a particular chart, separate the inner rose from the outer by using a stiff compass or dividers with a cutting point. With the rose face down on the table, apply several pieces of transparent adhesive tape around the edge of the cut between the inner and outer rose, but stick each to only one rose leaving half the tape protruding above to overlap but not touch the other rose. When the roses are precisely oriented with respect to each other, the projecting ends of the tape may be quickly adhered to the other rose. The rose is assembled face down so that the tape will not prevent direct contact between the positive image and the emulsion on the negative. Maximum tolerance in orientation of the magnetic rose is approximately $\frac{1}{4}°$ but the N-S points should be much less than that, so that there is no apparent error, with image distortion distributed between the E-W points in deference to the custom of making the N-S line the primary reference.

Numerical magnetic values are placed on the face of the rose and also any magenta features charted in the area covered by the rose. If such features include pen work, this may be done on a sheet of the same stock that the type is printed on, because it is sufficiently thin to avoid trouble in photoprinting, provides a grained surface for pen work, and can be easily removed to salvage the rose.

When you assemble waxed type for contact photoprinting, remove all excess wax which is forced out by pressure from the surface of the drawing, because this wax will stick to the negative emulsion and prevent the development of areas.

Use a scraper to remove this wax, because a solvent will also remove ink from the type.

Next draw the symbols to be used. These may be drawn in clusters for assembling as a unit where they are close together and film dimensional changes will have a negligible effect. From this transparent drawing, a film negative will be made.

When you start to assemble the negative, lay a clear vinyl sheet with the grained side up on the base lithographic zinc plate. The edges of the vinyl sheet should coincide with those of the zinc along the gripper (bottom) edge and the left edge for similarly locating images on both zincs. On this vinyl sheet, trace marks from the base plate with which to locate film segments, using a sharp, hard pencil or stylus and blue tracing paper.

Next remove the vinyl sheet from the base zinc. Stick the film segments lightly to a light table with their emulsion side down and with pressure-sensitive adhesive facing up. Then locate the vinyl sheet above each segment of film so that the feature on the film fits the marks traced on the vinyl sheet. This requires light from both above and below. As film segments are thus located on the vinyl sheet, exert a light pressure above the adhesive to make the film adhere to the vinyl sheet. Appropriate use of adhesives will ensure that the film sticks firmly to the vinyl sheet and loosens readily from the surface of the light table.

Since compass roses have projected marks beyond the extremes of the N-S and E-W lines, the film may be trimmed so that these marks intersect the edge. These may be used as a final check on accumulated error by laying the negative assembly over the base zinc plate and checking the fit between these marks and the coordinates or the parallel with which they should coincide.

Then place the vinyl sheet on a light table with the film segments down and cover it with a sheet of masking paper. This must also be laid so that the gripper and left edge will coincide with those of the vinyl sheet. Now, cut the masking

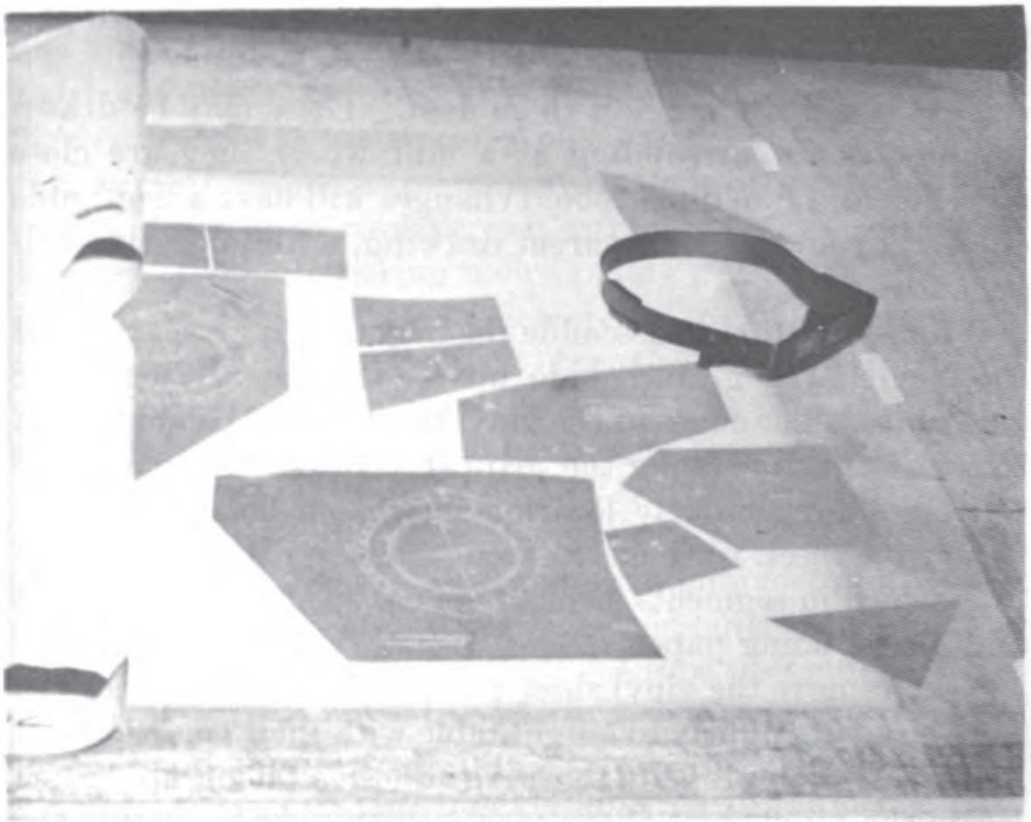


Figure 14–5.—A negative for a magenta plate assembled on a vinyl plastic sheet with the goldenrod mask rolled back.

paper away from the features to be printed. Figure 14–5 shows such an assembled negative on a light table with the masking paper rolled back.

Finally, retouch the assembled negative on the emulsion side with opaquing paint and erase from the vinyl sheet all reference marks over features.

After the plate is made, the assembly can be stored for future use but, because of the temporary or changing nature of features appearing on the magenta plate, it is usually simpler and cheaper to disassemble it. In this case, the vinyl sheet and the standard features may be returned to stock for reuse.

When a chart has a high density of features or when condensing the positive is impractical, the complete positive drawing, with the transparent type and compass roses, may be done on a transparent plastic sheet overlaying the base zinc

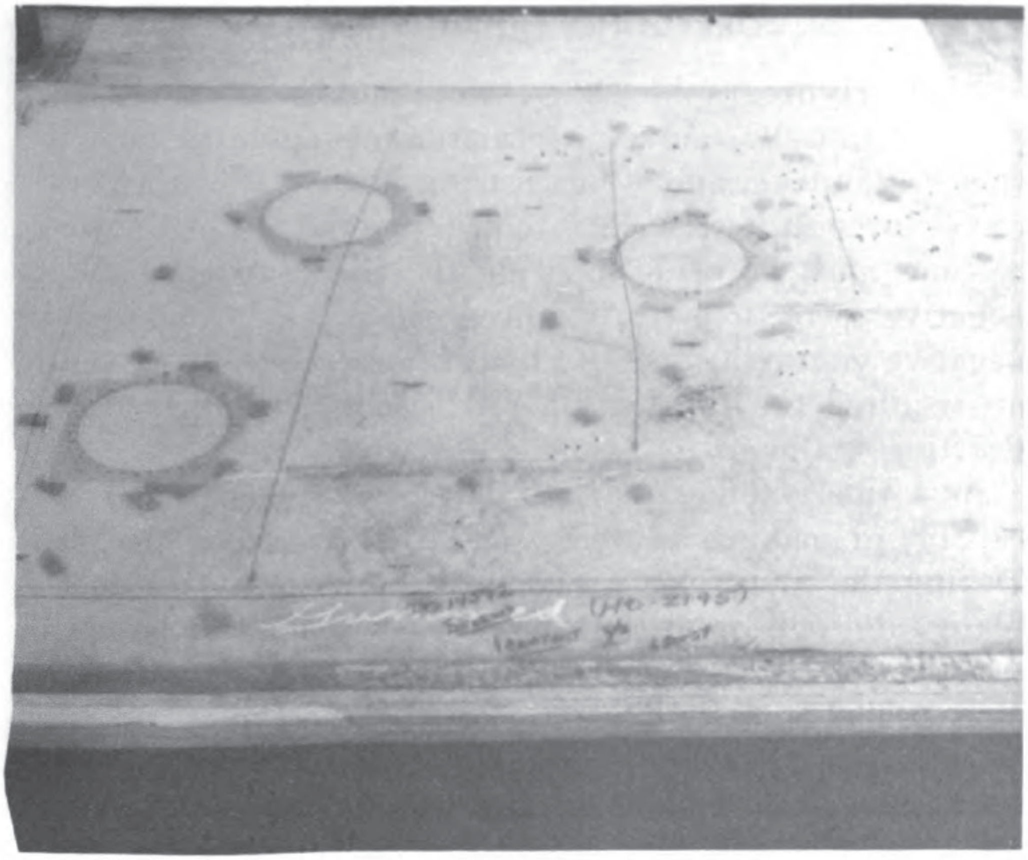


Figure 14–6.—Transparent original for a magenta plate drawn as an overlay on the base zinc plate.

plate. (See fig. 14–6.) In this case also, the gripper and left edges must coincide between the plastic and the zinc and all features are located in exact position relative to those on the underlying zinc plate. A contact film negative is then made and if the distortion of the film is within the tolerance in fit of features, it may be used in one piece.

However, if there is greater film distortion, the film negative may be cut and assembled on the back or below the original transparent positive drawing, with the features fitted to those of the drawing. If the positive is to be saved, a second plastic sheet may be fastened to the back of the positive and the film negative assembled on this. If the positive is not being saved, positive features may be removed from the top surface of the sheet, and then this is covered with masking tape to complete the negative assembly.

At the Hydrographic Office, samples of each printed chart are kept in a file, and as information changes, the compilation section makes notes against the chart. When an order comes through for the chart to be reprinted, all of these corrections must be made to bring the chart up to date. If negative corrections are required, the work is done in the negative engraving section, but if corrections to the plate are required, the information will be sent to the lithographic drafting section.

As a rule, it takes years to develop a trainee until he is capable of making any necessary corrections on the plate. During the first year, a man may be assigned to do tint plates, and outside of that, his work will consist largely of practice jobs. New men generally start by learning to do large roman letters. They work with pencil until they have learned letter construction and spacing. Then they begin to work directly on the zinc with pen and tusche. As their skill increases, they are assigned more difficult jobs. (See fig. 14–7.)

When a plate is to be corrected, it is first pulled from the file and sent to the transfer section. There it is rolled up and areas are deleted if necessary. Next it is counteretched with a solution that makes it sensitive to grease in the areas that are to be corrected. At this point, transfers of seals and notes are made. Then the plate is forwarded to the lithographic draftsman who does freehand corrections.

If the areas in which the corrections are to be made are fairly complicated, the transferrer may leave the job of counteretching to the draftsman. In this case, you should sensitize the areas locally as you go along. Never sensitize large areas and leave them in the open too long, as weather conditions sometimes cause the inked image to spread. It is best to gum the areas as you complete them, and to keep the remainder of the image under gum until you are ready to work on a particular area. You can then remove the gum with water and sensitize the area with cyanide. Use a strong

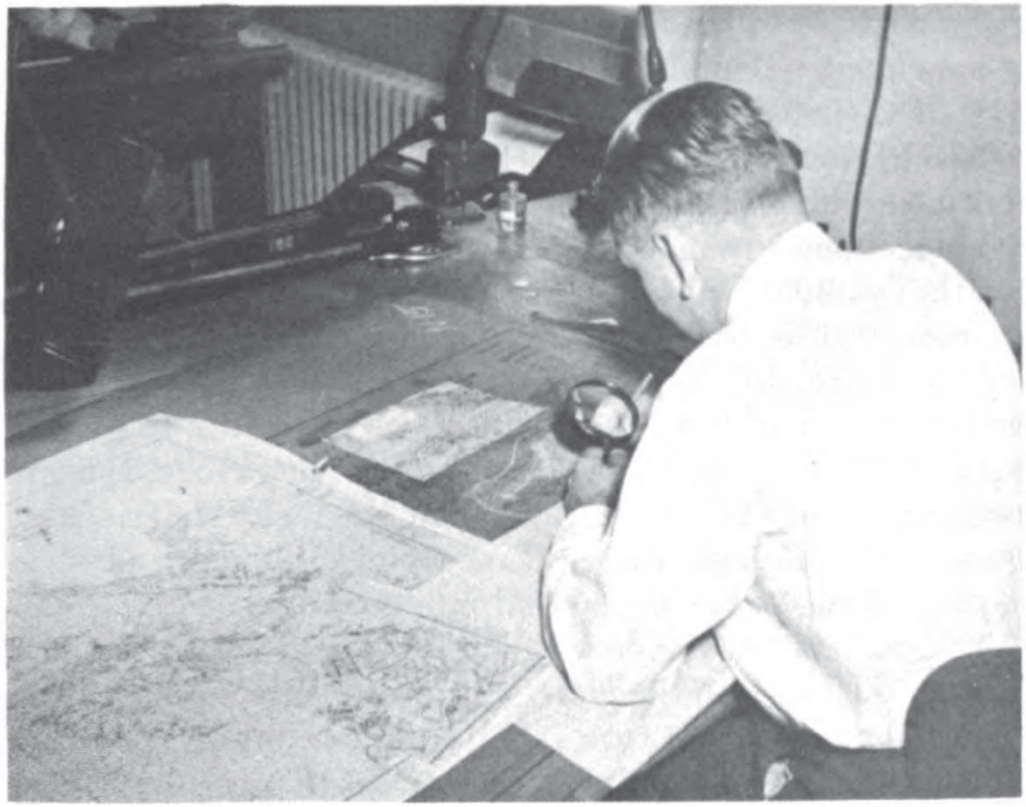


Figure 14–7.—Drawing the corrections to a chart directly on a lithographic plate is a tedious operation, requiring a wide knowledge of the different features to be drawn, as well as the ability to work in a number of different styles with difficult mediums.

(brown) solution of cyanide to clean out areas covered by developing or transfer ink. The cyanide may be followed by abrasives if necessary.

You may find that it will be necessary to treat open areas of the plate with cyanide before you can work on them. The transferrer uses various solutions on the plate, and it is practically impossible to work over the coating left by some of these chemicals. He will generally write the name of the solution he used in the corner of the plate so that you can tell whether you can draw directly on the plate or whether you must first sensitize the areas with cyanide.

The problems involved in making corrections on the plate are connected with maintaining proper physical and chemi-

cal conditions so that the chart will process correctly when it is printed. Conditions of humidity may affect the work, as well as the skill of the draftsman. Usually each man develops his own methods of working, using the materials and mediums which work best for him.

If deletions are small, you may simply use abrasives without the cyanide. However, abrasives may be followed by the cyanide, if it seems desirable. You may make deletions with a retouch transfer eraser, which is a rubber eraser impregnated with pumice. However, it is very difficult to get the surface clean enough with this eraser and, therefore, using it requires considerable care. You can also make deletions by going over the lines with a Tam O' Shanter hone or slate stone. Etcho sticks or snake slips may also be used.

In removing the image with abrasives, you will sometimes destroy the grain on the plate. This will leave smooth areas that will not hold moisture. If the plate is put on the press, these areas can pick up ink. To prevent this from happening, you should regrain the areas by going over them with pumice powder and cotton. You can also restore the grain by rubbing the plate in a light, circular motion with aluminum oxide powder and cotton or a piece of cork.

If additions are necessary, you may sensitize the areas of the plate in which they are to occur by applying a weak (clear) solution of cyanide. Let the cyanide stand on the plate for about a minute (depending on its strength) and then wipe it off. Next, apply phosphoric solution for a minute and wipe it off. A strong solution of cyanide will burn the image off the plate, and this may also occur if the cyanide is left on too long. The phosphoric solution will not affect the image regardless of how long it is left on.

Next, find the position for your lettering or other work. For lettering, you may draw in guide lines with a three-pronged stylus. This instrument is called a gage. Gages are supplied in varying sizes to match the point-size of type faces. There are 8-, 9-, 10-, 18-, and 24-point gages. The bottom and top prongs of the gage furnish the guide lines for

your capital letters and the middle prong produces a guide line for the tops of the lowercase letters.

Lines and other work are not drawn directly on the plate. Usually all work is sketched or laid out on engravers' gelatine. This is then dusted with blue powder and burnished on the plate. Lines may be pressed on through a blue-chalked paper something like carbon paper except that it is not greasy. The reason for this is that any grease adhering to the plate may print. When you press the three-pronged gage against the face of this paper, chalked lines will transfer from the back of the paper to the plate. You can then construct the letters freehand, using tusche and a lettering pen. Always make sure that there is no grease on the surface of the chalked paper, and do not press so hard that the prongs of the gage cut through the paper and dig into the metal surface of the plate. Scratches in the plate may print when the job is run on the press.

After you have made the corrections, you should take a piece of chalk and encircle the areas where you worked as shown in figure 14–7. This is done to call these areas to the attention of the transfer room where the plate is to be etched.

Corrections may also be made on a zinc plate after it has been placed on the press, provided the corrections will not take so much time that the operation of the press is held up excessively. The draftsman who makes such corrections must be so skillful that he can work under difficult, cramped conditions.

LITHOGRAPHIC TRANSFERS

Not all additions to the plate are made by the lithographic draftsman. In some cases, dot patterns, seals, notes, and so on are applied to the zinc in the transfer section. These features are first printed on a paste-coated paper with a greasy ink especially adapted to this purpose. Since the print is made on the paste-coated side of the transfer paper, the layer of paste prevents the ink from penetrating the paper. Standard plates, consisting of dot patterns, seals,

and other features common to charts, are used in the printing of these transfers.

The operation of transferring consists of inking the design on the standard plate, laying a piece of transfer paper over it and running it through a press under pressure. The transfer paper is then removed from the plate, and the freshly-inked design is ready for transferring to the chart plate. The transfer is carefully positioned on the chart plate and applied to it face down. If the transfer is to cover a large area, the plate is run through a pressure press, but if the design is small, a hand roller may be used to provide the transfer pressure. In either case, the pressure causes the transfer to adhere firmly to the plate. After this, water is applied to the back of the transfer until the paper is saturated and the paste dissolves. The paper is then removed, leaving the transferred design, in greasy ink, clear and sharp on the surface of the chart plate.

CORRECTING EXISTING NEGATIVES

Sometimes, corrections are made on the wet plate negative. Deletions may be made by opaquing, and additions may be made by hand engraving. Although the negative engraving is generally done in a separate section, you may occasionally be called on to do this type of work. (See fig. 14–8.)

Opaquing operations are similar to those performed on contact negatives for magenta plates, except that you will be working on glass instead of film. Place your negative on the light table. Then test your opaque by applying a little of it to another piece of glass. If it appears translucent, that is, if the light shows through, it is too thin. If it is lumpy, it is too thick, and solvent should be added.

After the proper consistency has been reached, fill your brush with opaque and twirl the round tip of the brush once on a piece of scrap paper to obtain a point. Then lightly spot out the areas to be deleted with the tip of the brush. You can paint out large areas with a half-inch chisel-edge brush. Use flat, parallel strokes and avoid painting over

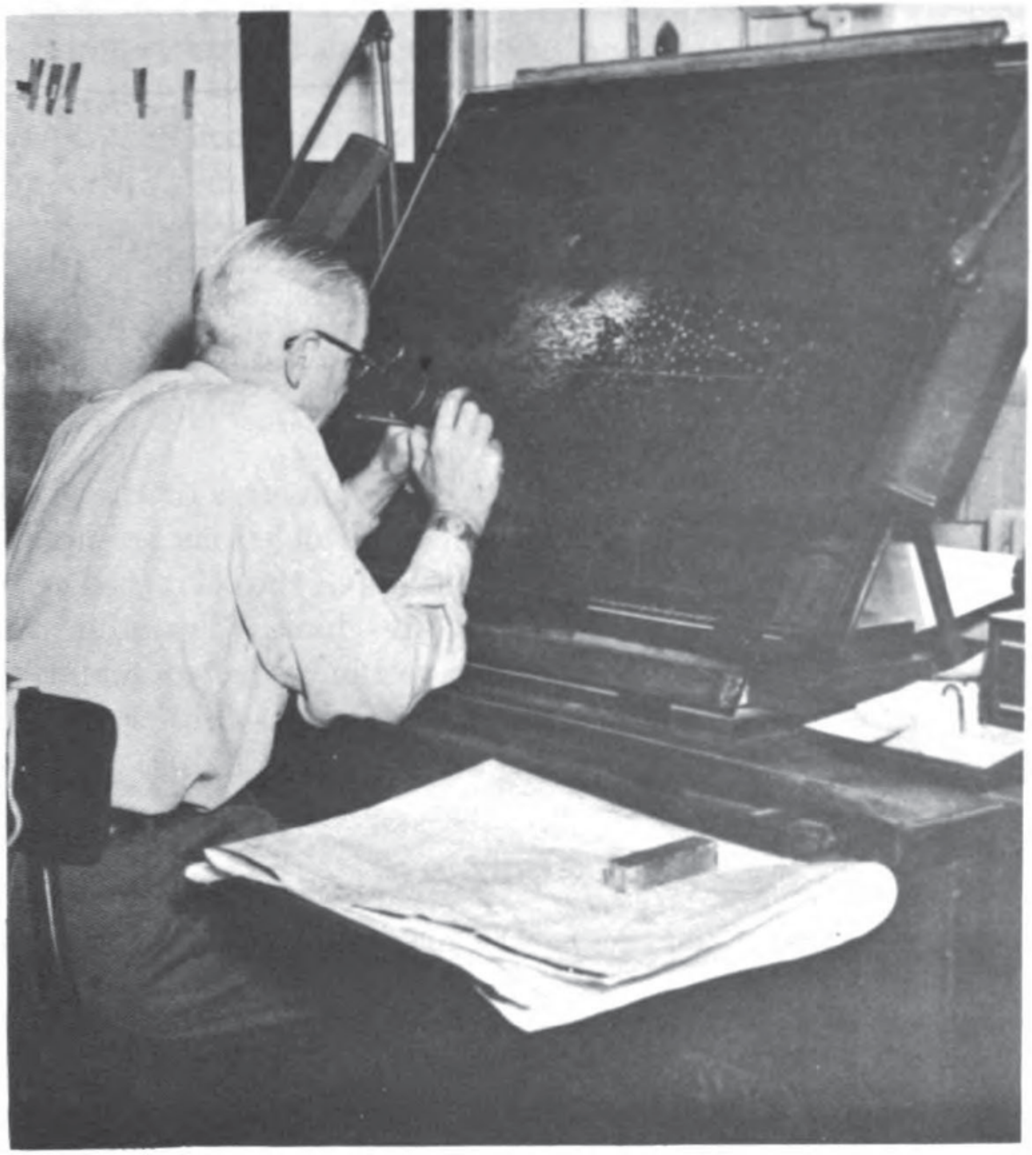


Figure 14–8.—Engraving corrections on a glass negative requires many of the same skills as correcting a lithographic plate, but on the negative the lettering must be engraved in reverse.

areas, as this develop ridges. Start at the center of the negative and work down so that you will not smear the work. You can steady your arm on an arm board or on a piece of soft blotting paper. This will prevent the scratching or smudging of the negative emulsion.

There are special tools available for engraving negatives. Tools have been designed for cutting single or double lines, as well as for lettering and figures. Some of these tools are

constructed to provide uniform pressure, width, and angle, but in most cases, the handling of the tools depends upon the skill of the operator.

Lithographic needles look like oversized pencils. They have a steel cutting edge that is generally round, although flat ones are sometimes used. Round needles come in sizes from 00 to $\frac{1}{16}$ of an inch, and flat needles range from 00 to $\frac{1}{4}$ of an inch. You may sharpen the needles to suit your purpose. Before you begin work, you should test the engraving tool in the margin of the negative. Test marks can be touched out afterwards with opaque.

When it is necessary for you to correct an area of the glass plate, opaque out existing work whenever deletions are necessary. Then make a tracing on celluloid of the corrected area and fill the scribed lines with white chalk. Transfer the tracing to the negative and engrave the corrected material into the emulsion. If the emulsion tends to chip or crack, go over it with a thin coating of asphaltum before you do your engraving.

QUIZ

1. What is the printing process which is generally used for printing charts?
2. Why are glass negatives used instead of film negatives in chart work?
3. What is meant by a two-negative job?
4. How is goldenrod paper used?
5. What is tusche?
6. Why should you encircle with chalk those areas where you have done handwork on a plate?
7. What is the name generally given to plates that are to print in gray or blue?
8. What is the black plate generally called?
9. What is meant by a blueline plate?
10. When is the chalk powder offset process used in preparing tint plates?
11. Why is magenta ink used for printing certain information on a chart?

12. Why is a tint mask prepared rather than a zinc plate when large quantities of a chart are needed?
13. What can be added to the ink used on acetate to help prevent its chipping or cracking?
14. What is a gage?
15. Why is the gage not applied to the plate but used to press on the lines through a blue-chalked paper?
16. How are deletions made on wet plate negatives?
17. What is meant by "wax type?"
18. How can you prevent the emulsion on a glass negative from chipping or cracking as you engrave it?

CHAPTER 15

LAYOUT AND ILLUSTRATION

INTRODUCTION

Although your work will consist of what is called commercial art, you, as a draftsman illustrator, should have an understanding of line, form, tone, and color which is equal to that of an artist. Fine art is to commercial art what scientific research is to the sciences. Without the fine arts, commercial art would soon lack vitality and originality. Many of the best commercial artists are also fine artists and carry over to their commercial work the daring, originality, and awareness of beauty that make them noted in the fine arts.

Commercial art differs from fine art in only one important respect. It is the business of a fine artist to communicate his own feelings; a commercial artist, on the other hand, is usually asked to work on something in which he has no personal interest. Insofar as he is able, by an exercise of imagination, to develop real feeling about, or interest in, each thing that he does, he is a better artist.

When you do an illustration or a layout, it is most important to keep in mind the purpose for which it is intended. No matter how technically perfect it may be, it has failed if it does not tell the story. The artist should be able not only to visualize his subject matter but also to imagine the reactions of the unseen audience for which it is intended.

Styles in illustration and layout, like styles in clothes, change along with subtle changes in the ways people think and do things. Also an artist's style is his means of conveying ideas and emotions, and a style which is not appropriate

to the audience for which a piece is intended can defeat its purpose. In order to help develop an awareness of style, keep a personal file of recent magazine illustrations and publications that have styles which seem interesting to you. When you see something that has a fresh approach, get a copy of it and stick it in your file. It may give you an idea that you can use to advantage later. However, never copy an illustration or layout exactly. Use the ideas of others as stepping stones to your own ideas, but do not use them as crutches.

LAYOUT

LAYOUT is a term that is used to mean different things in different fields. When it is used in referring to an illustration, it refers to the plan of a picture or design, especially the preliminary drawing as distinguished from the finished drawing or rendering. However, LAYOUT is used almost exclusively in referring to the plan for something which is to be printed, like a poster or a publication. Poster layout has been discussed briefly in *Draftsman 3*, NavPers 10471.

The layout artist must have a knowledge of printing, binding, and related trades. Unfortunately, he is rarely at liberty to develop the most attractive and appropriate layout he can. Usually, he is limited as to the size of the publication or poster, the format, and the paper and ink to be used for the printed job. All this means that, in order to do a layout which will serve the purpose, he needs more knowledge and imagination, rather than less.

For more technical and detailed discussions of printing and type than can be included in this chapter, read *Lithographer 3 and 2*, NavPers 10450, especially the chapters on selecting the type face and planning the job, and *Printer 3 and 2*. If you can, obtain copies of the *Armed Forces Newspaper Editors' Guide*, NavPers 10293A, and *Planning and Preparation of Navy Department Publications*, NavExos P–385, to add to your own or your section's reference library.

In most publications, the pages are vertical or horizontal

rectangles. Squares, circles, or irregular outlines are rarely used. The early books may have followed the rectangular shape because men were accustomed to rectangular windows and doors. Also, the animal skins from which vellum and parchment were made were roughly in the shape of rectangles, and it was more economical to cut rectangular shapes from them.

Today, paper is manufactured in rectangular sheets, and it continues to be more economical to cut and fold them in rectangular shapes. When a sheet of paper is folded once and then trimmed, it makes 4 pages. Folded three times, it makes 16, and four folds make 32. Pamphlets and books should be designed around these units, which are called signatures.

Composition

Since in any two layouts, the elements, or parts, are never the same, you cannot use a set of readymade formulas to compose a layout. You must depend on what looks best to you, designing each job individually according to the proper specifications.

First, analyze the elements that are to go into the layout. Determine which is the most important so that it may be given greatest emphasis. Then try to get a mental picture of the elements as they will look when they are printed. This takes practice, but a layout man should learn to think in terms of the finished product from the first. The drawing which he makes is a blueprint for a page. The test of his ability lies not in the finish of the drawing but in the final success or failure of the page he plans.

You may find that it is impossible at first to visualize the complete layout mentally. You can start by visualizing the separate elements, drawing them roughly on separate pieces of paper, and then placing them on a layout sheet. When you see them next to each other, some may seem too large or too small or they may not harmonize with the other elements. Redraw these and move them about in relation to each other until you get an arrangement that looks good to you. Then

trace this on a new layout sheet and refine it until it looks finished.

Some men start by drawing thumbnail sketches and selecting the best one to work up into a finished layout. The small size of a thumbnail makes it easier to see the pattern as a whole. However, you may find that something which looks good when it is small, loses its sparkle when you enlarge it. If you do preliminary thumbnails, be careful not to give more weight to a line of type than it can possibly have in the full-size layout. The type faces available in large sizes are limited.

Composition can be said to be the art of relating contrasting elements. The color of ink in which the type is printed contrasts with the white paper. The gray tone of a block of body type contrasts with the larger, darker headline type.

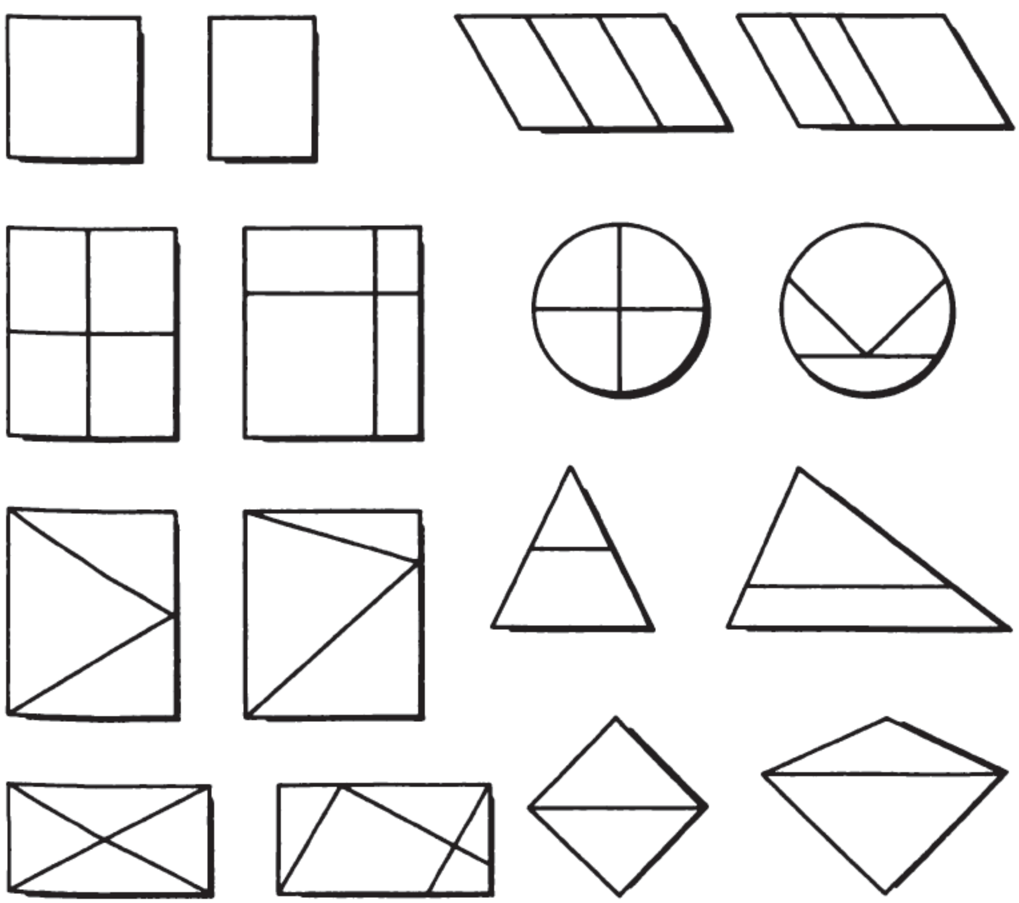


Figure 15–1.—Comparison of various proportions.

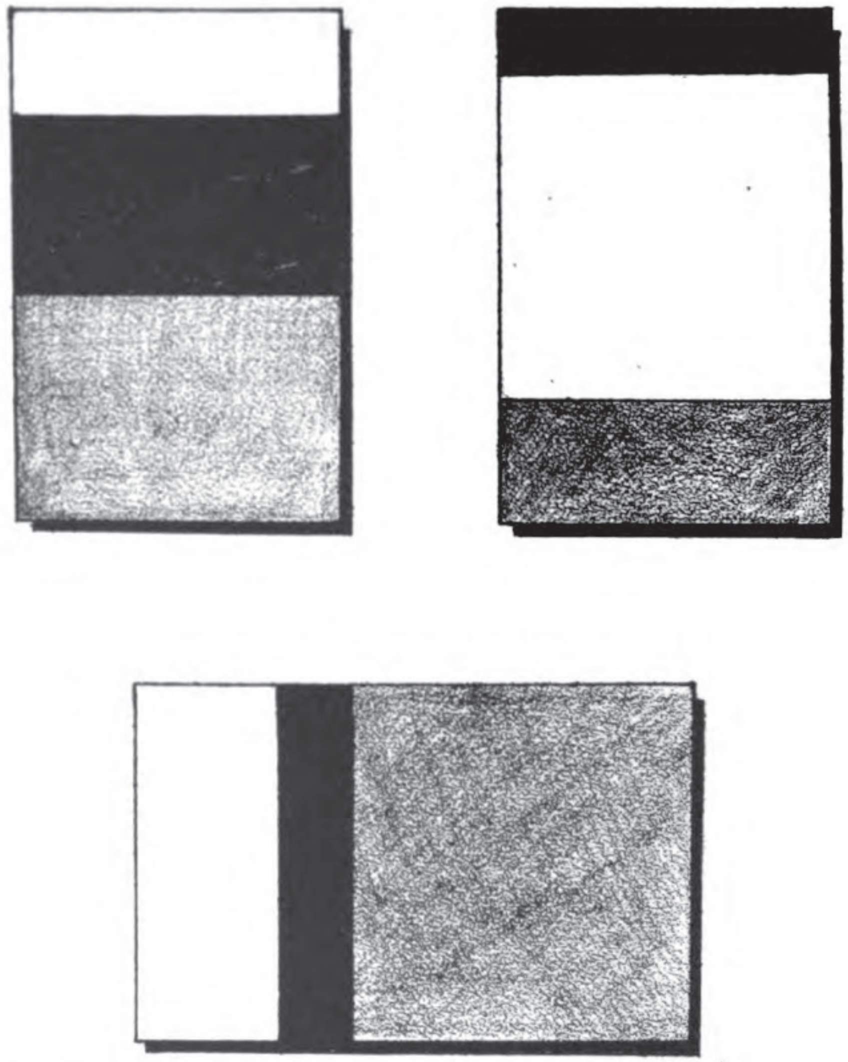


Figure 15–2.—Rectangles with the proportions rendered in tone.

An illustration, whether it is a line cut or a halftone, presents a distinct contrast to both the paper and the type.

If there are too many contrasting elements or if they are unrelated, the composition will confuse the person who sees it. If he can't decide where to look first, he may decide not to look at all. On the other hand, if the composition is lacking in contrast, it will be dull, and if contrast is lacking altogether, as in the case of type printed in gray ink on gray paper, it will not only be dull but almost impossible to see.

Contrasting elements may be related to each other and the composition unified by various methods. One method of

relating the elements consists of planning them so that the resulting proportions are pleasing. Figure 15–1 shows how a rectangular area can be divided in differing proportions. Notice that one of the rectangles is divided into a number of squares which are all the same size. Its proportions are less

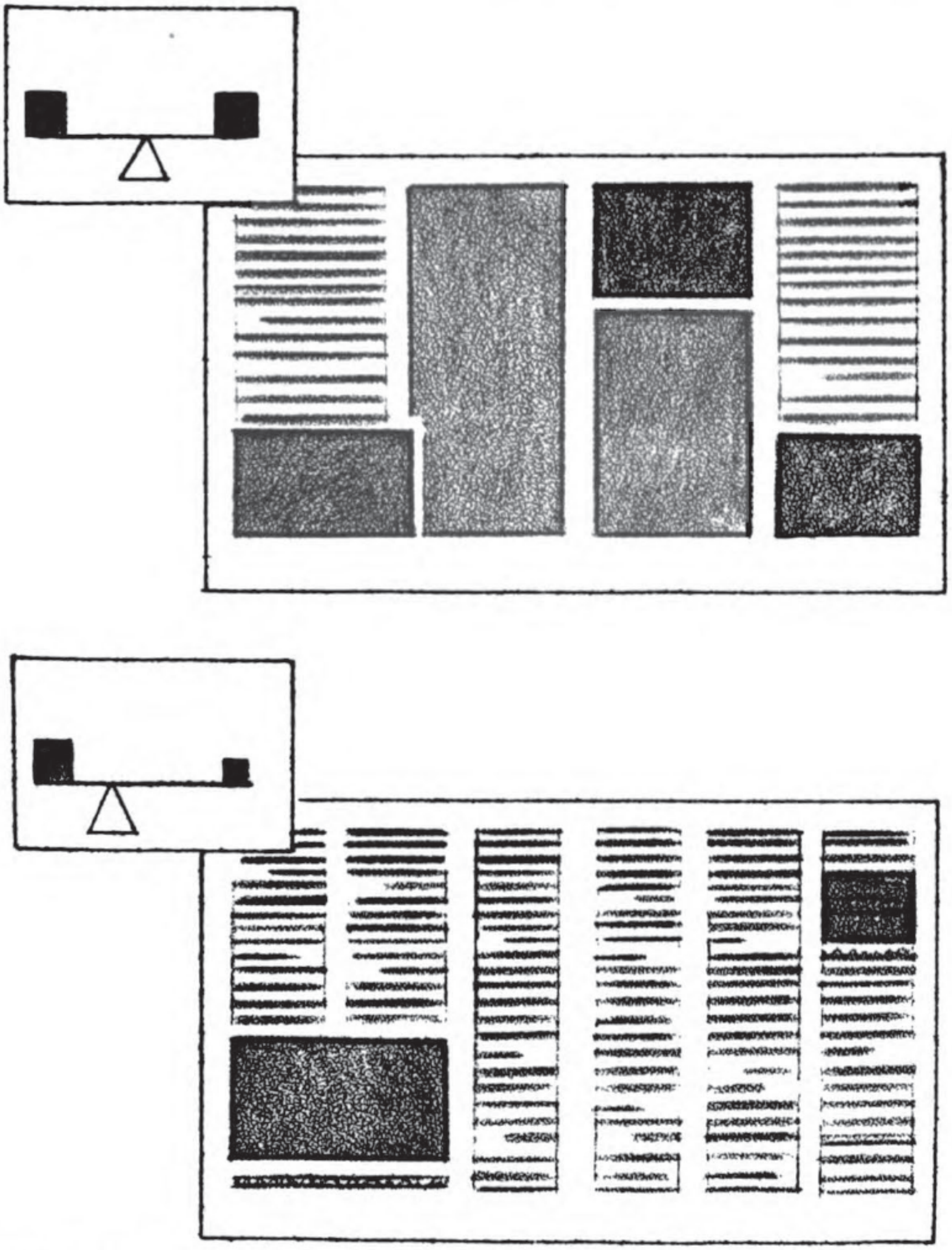


Figure 15–3.—The principle of balance is the same for a seesaw and a layout.

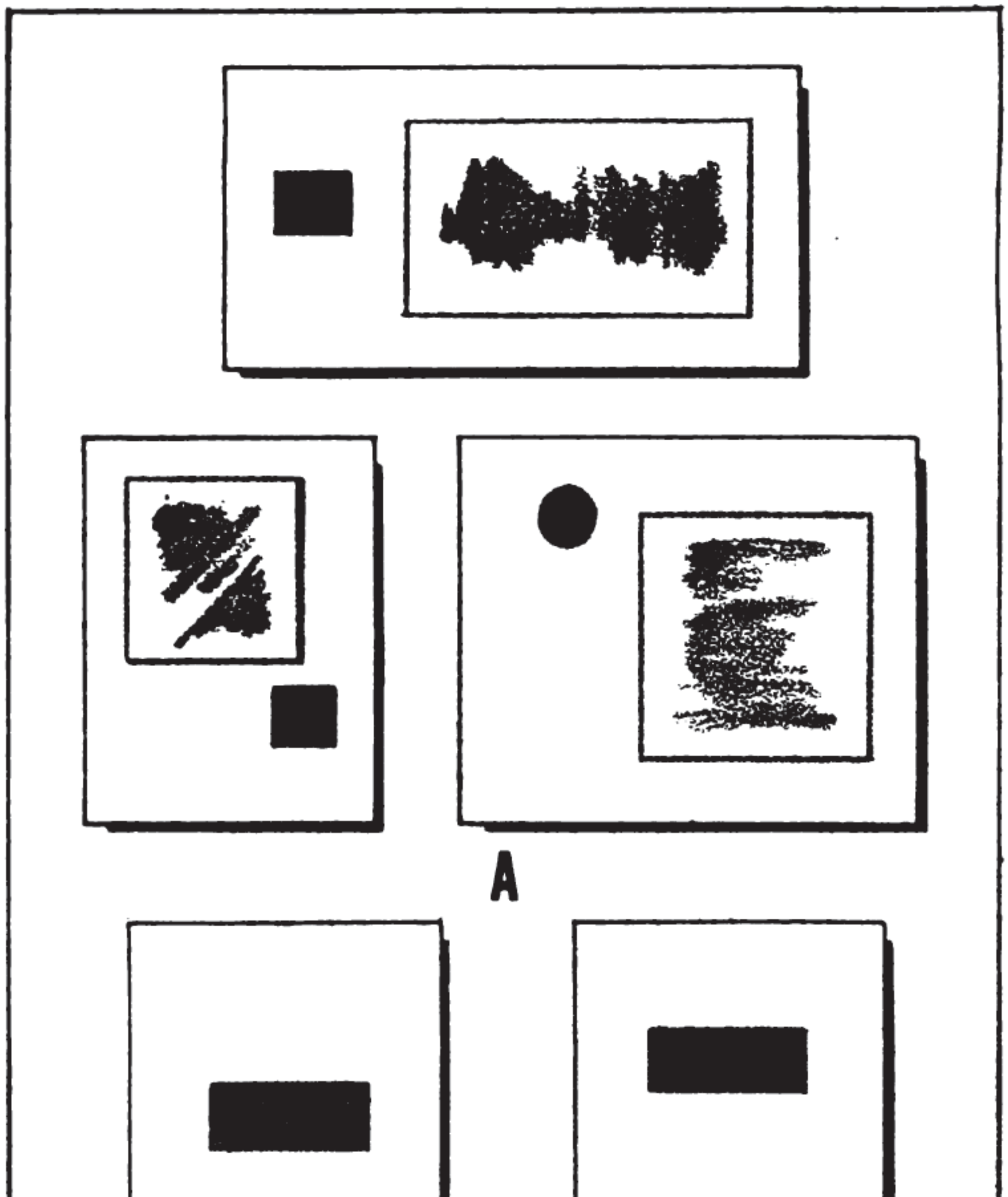


Figure 15–4.—A. Examples illustrating balance in layouts. B. Center of the page. C. Optical center of the page.

interesting than those of the rectangle next to it, because it is monotonous.

In figure 15–2, rectangles with interesting proportions are shown in different tones. A black, a white, and a medium gray are used. This type of treatment works well for a layout of a pamphlet cover. Wherever several tones are used, the layout will be more interesting if one of the tones clearly dominates the others, either in size or intensity.

Another method of relating the elements consists of balancing them. The principle of balance is the same for a seesaw and a layout. Look at the layouts in figure 15–3. In layout, a small dark element can be used to balance a larger, lighter element. Examples of this kind of balance are shown in figure 15–4A.

The optical center of the page is slightly above the actual

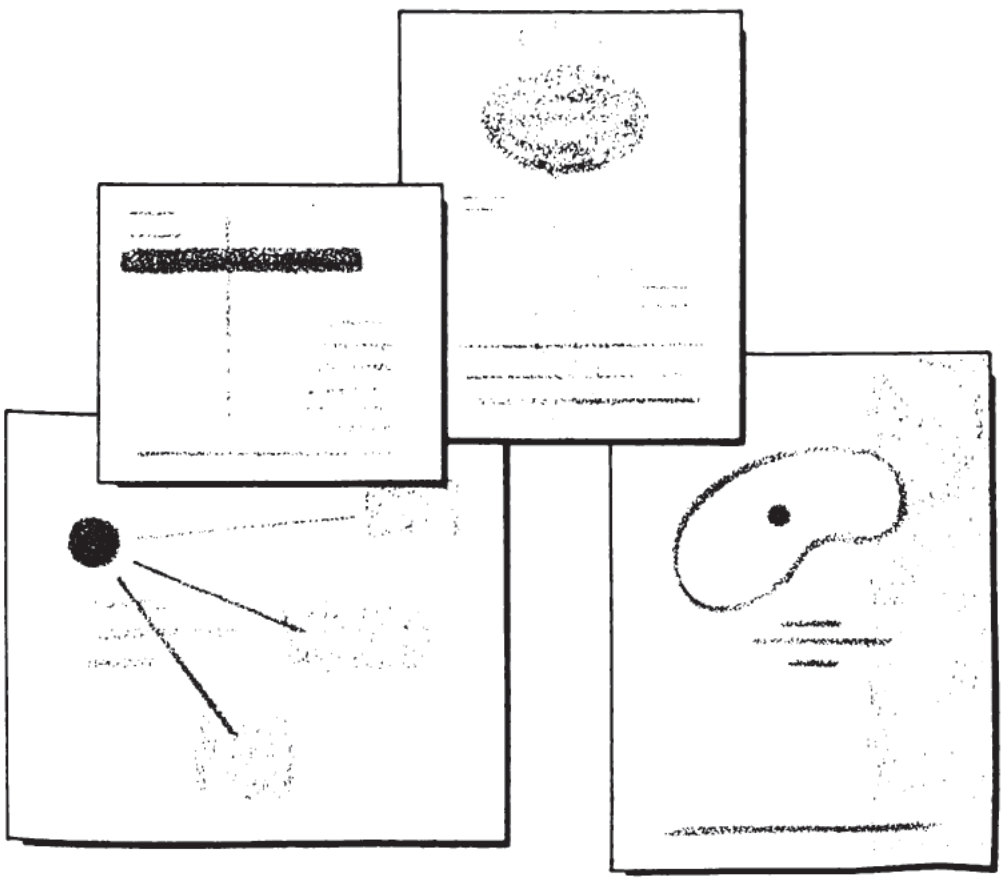


Figure 15–5.—Examples illustrating grouping of elements.

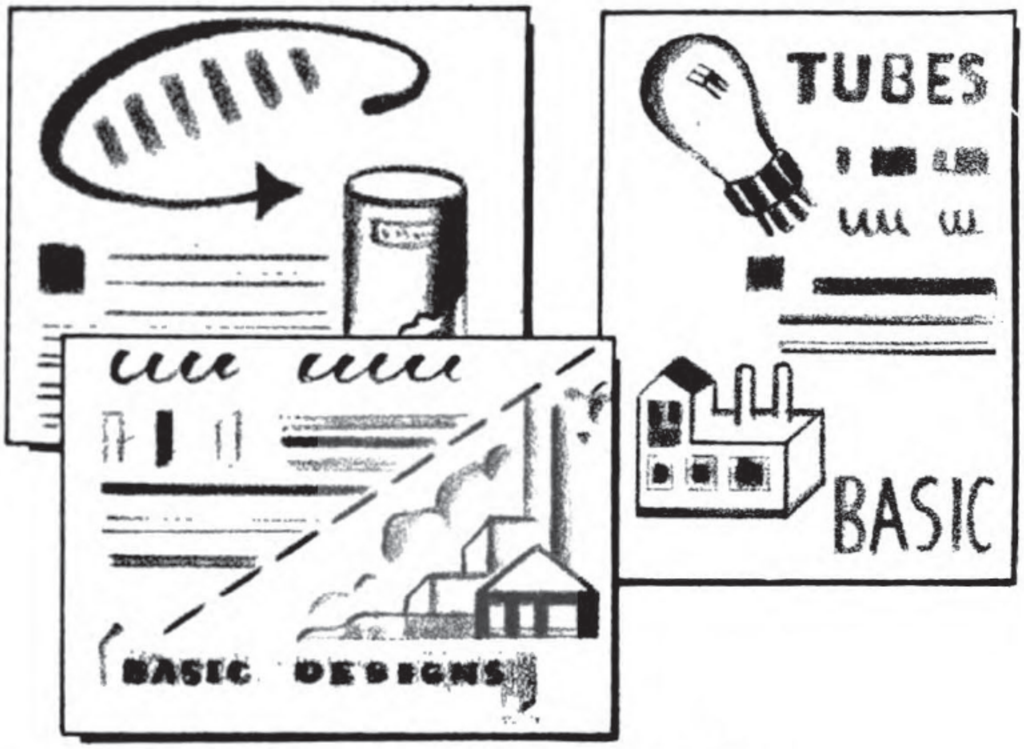


Figure 15–6.—Examples of direction in layouts.

center. When an element is placed at the exact center, it does not look as well balanced as an element placed slightly above. (See figs. 15–4B and 15–4C.)

You can also relate a number of elements by grouping like elements together. These groups may then be positioned on the layout in a simple pattern. Examples of grouping are shown in figure 15–5.

Another method of relating could be called the direction or rhythm method. You can arrange the elements in a layout so that the eye is naturally led from one to another. (See fig. 15–6.) This eye-leading arrangement is particularly important in display work. It is also useful in publication layouts, where an illustration or a caption can lead the eye to the reading matter or, failing in purpose, away from it.

Materials and Methods

The layout man's tools consist of drafting equipment on the one hand and reference materials on the other. Compli-

cated layouts may require the use of india ink, chinese white water color, tempera colors, or pastels. You will need a line gage or pica rule, also called a printer's rule, and you will find a reducing glass useful. Through the reducing glass, you can see approximately how art or type will look when it is reduced to the printed size.

Reference materials include paper samples, type specimen books, and a morgue or file of layouts and drawings. You should also have proofs of all the types, borders, ornaments, and cuts available at the print shop where your layouts are usually printed. Other reference materials which you may find of use are copyfitting charts, paper allowance lists, and samples of different types of paper stock.

Tracing paper, available in pads of varying sizes, is useful for layouts because it is sufficiently translucent to enable you to trace type and illustrations. Since ink or water colors will usually cause the paper to wrinkle, you should work with pencil on tracing paper. Crayons or pastel sticks may be used when large areas are to be filled in with color. If you apply these colors to the reverse side of the sheet, they will show through to produce a toned or shaded effect. When pastels are used they should be sprayed with a fixative solution to make them less likely to smear.

If you use tracing paper, you can draw the layout roughly on the top sheet of the pad, erasing and altering until you get a composition to your liking. Then tear this sheet off and slip it under the next one. The drawing will show through clearly, and you can trace the elements, refining lines and changing tones. This can be continued until you are completely satisfied with the composition of the layout. The final version may be traced on, or transferred to, a sheet of white bond, which also comes in tablet form and which provides greater contrast with the dark pencil lines.

When you use tracing paper, you can shift the various elements of the job with a minimum of effort. If your original layout isn't pleasing, you may place a clean sheet of tracing paper over it and trace off the elements, shifting the paper to change the location of the units as you see fit.

Newspapers and magazines often furnish layout sheets, like those shown in figure 15–7, to the layout man. These sheets are the same size as the page and are printed with lines showing the column or type page width and depth.

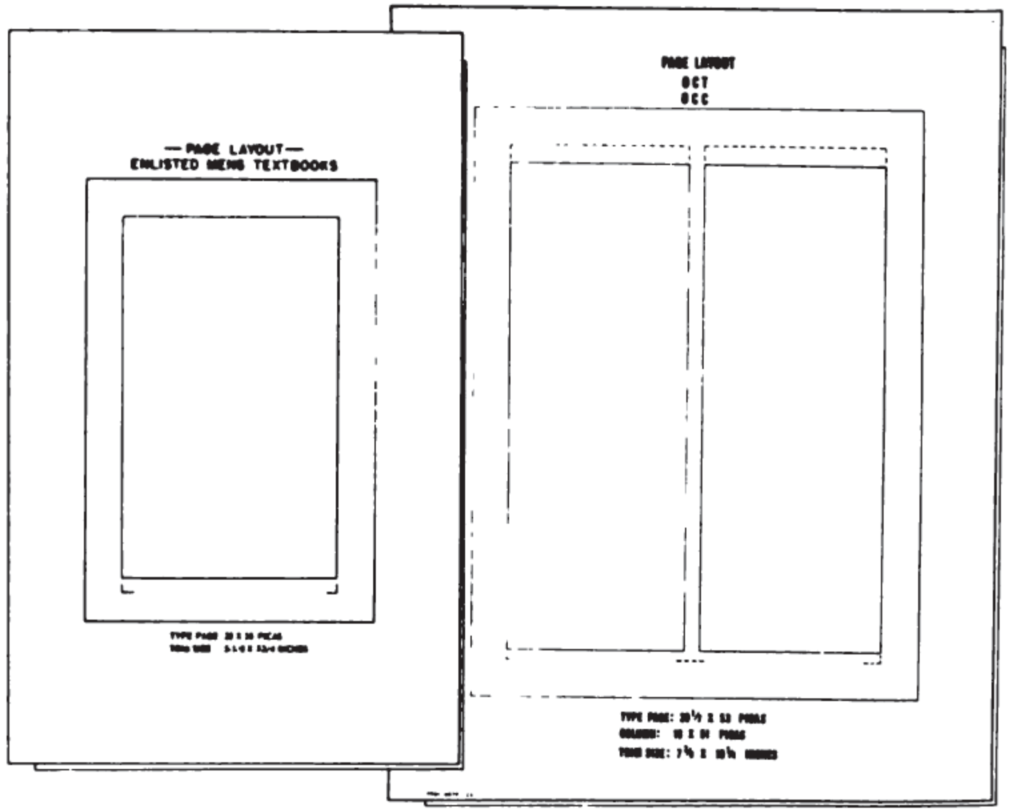


Figure 15–7.—Layout sheets for publications.

To transfer a layout to a new sheet, rub the back of it with a soft graphite pencil. Then lay it face up on the sheet of paper and trace over the original elements with a sharp, hard pencil. This will produce a clear outline of the original layout on the drawing paper.

A flat carpenter's pencil is good for shading large areas and getting flat tones. Color may be applied with water color washes, colored pencils, or pastels, although color is rarely required on anything but comprehensives. In doing lettering on a layout, use a 4B or a 6B round pencil. Professional layout men often sharpen these pencils to a long point and then use a sandpaper pad to flatten the point to a

chisel edge. The width of the tip of the pencil controls the width of the strokes of the letters. (See fig. 15–8.) The pencil may be held in a position which is perpendicular to the paper rather than in the usual writing position.

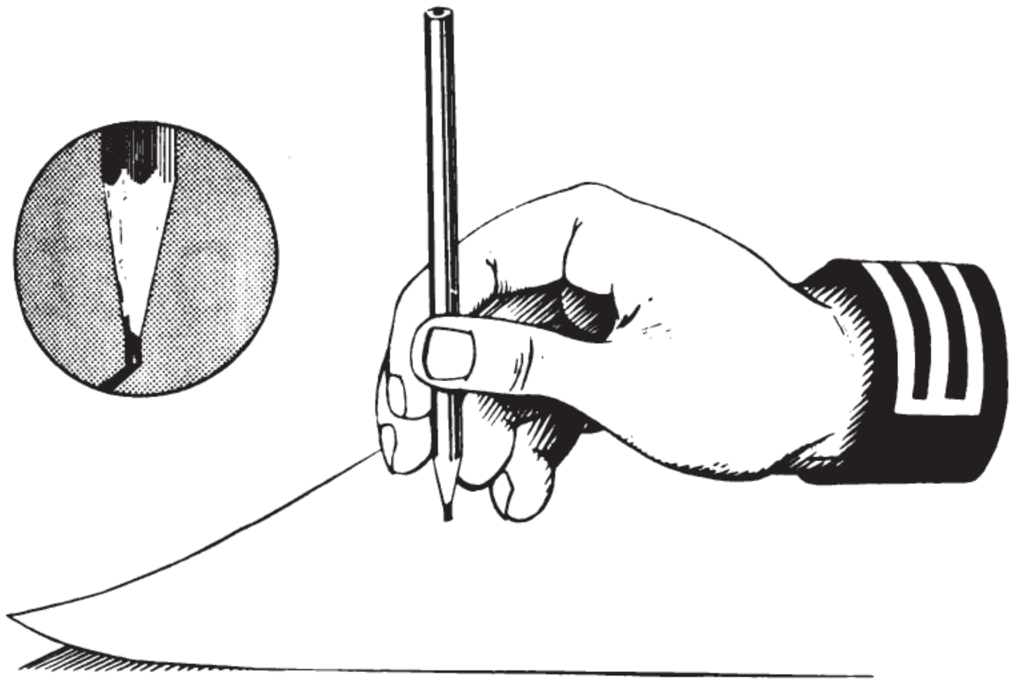


Figure 15–8.—Position sometimes used in lettering with a chisel-point pencil.

For gothic letters, the pencil must be turned each time the stroke takes a new direction. (See fig. 15–9A.) For roman letters, the thin side of the chisel is used to make the thin strokes and serifs. (See fig. 15–9B.)

With a little practice, you will be able to make letters that have the rough characteristics of different type faces. Until you have acquired this ability, and even then, whenever the exact spacing of the lettering is important, you can trace any display type from a type sample of the correct size and weight.

Experienced layout men use the T-square not only to draw horizontal lines but also to draw vertical ones, thus eliminating the need for a triangle. (See fig. 15–10.) First, tack the sheet of layout paper in place on the drawing board, or if you are using a pad, place it so that it will not slip. Then,

Figure 15–9.—Gothic alphabet above; roman alphabet below.

position the **T**-square, with its head against the side of the drawing board, so that the lower edge of the blade rests on the paper where you want the top of the line to fall. Place your pencil point against this blade. With the point held firmly against the blade, grasp the head of the **T**-square and slide it toward you until the line is the proper length.

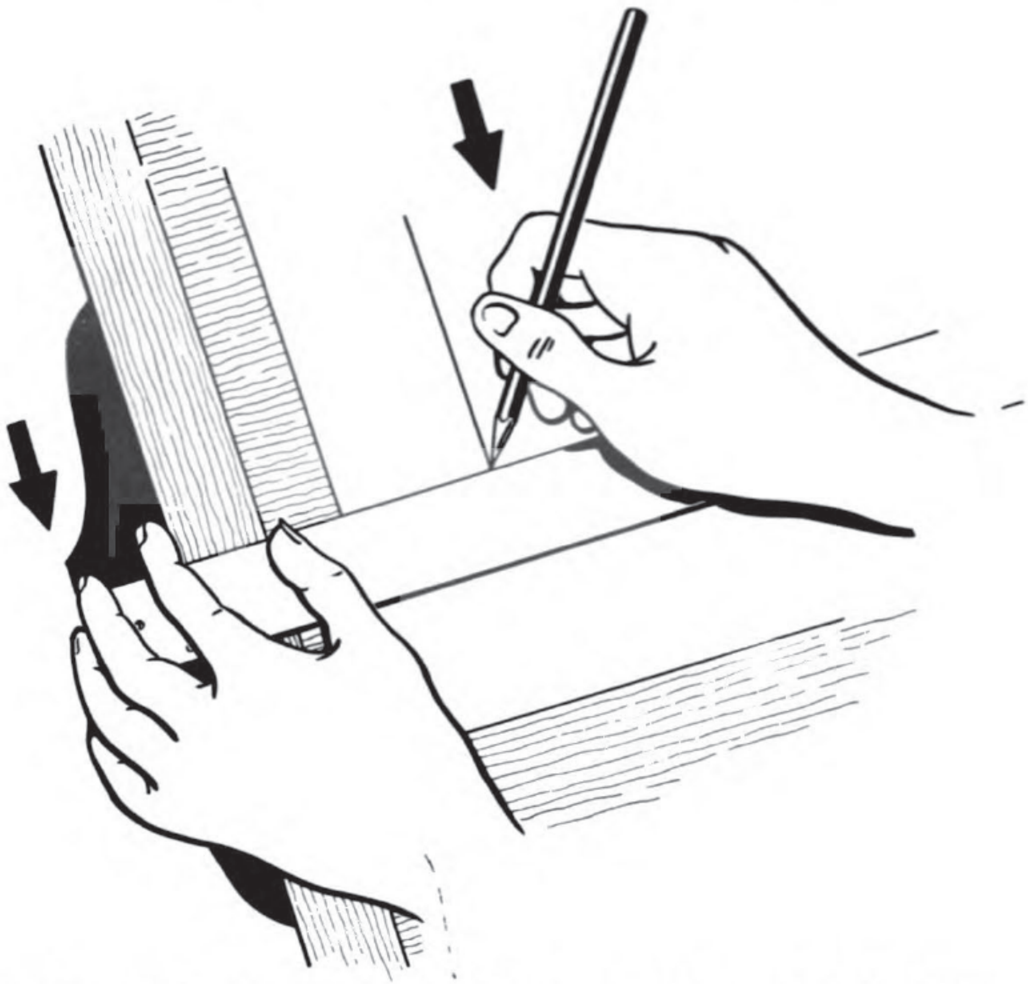


Figure 15–10.—Method of using a T-square to make a vertical pencil line.

Type

Blocks of type print as various tones of gray, depending on the thickness or weight of the type face and the amount of spacing used between the lines. You should use dark tones of heavy type sparingly as too much black makes the page difficult to read. The text or major portion of the copy should be set in a type that will produce an over-all

gray effect on the printed page. This gray tone may then be accentuated with dark tones produced by larger, heavier type used for headings or titles that require emphasis.

The size of type is specified in points. There are 12 points in a pica and approximately 72 points in an inch. Display type is usually considered to be the 14-point faces and larger; body type, the 8-, 9-, 10-, and 12-point faces which are generally used for text.

Different classifications of type are discussed in chapter 12. For an excellent discussion on how type is set and how to select the right type for the right job, read chapter 2, *Lithographer 3 and 2*, NavPers 10450. Also visit your ship's print shop or a good commercial print shop and learn how type and cuts are fitted together in printing. You cannot begin too soon to think in terms not only of tones on white paper but also of blocks of metal type, cuts mounted on wooden blocks, and metal spacing strips which do not print but which keep the type and cuts in position. In the case of offset printing, you must also visualize the page as a photo negative, or a group of negatives pasted together. Your layout will fail, no matter how pleasing it is on the drawing board, if you ask the impossible of the printer.

When you select display type, choose a face which fits the mood of the subject matter of the copy and that goes well with the body type to be used. In selecting a body type, pick one that is easy to read. Unusual faces are difficult to read and defeat their purpose.

In general, the simpler the style of the letter, the easier it will be to read. Open, clean-cut letters with plain serifs are best. The serifs lend unity to the letters, binding them together as words. That is why roman type faces are generally chosen for body type. Since the eye has more difficulty scanning blocks of type set in unusual type faces, such faces are generally used only for cut-lines, headings, and display work. Although sans-serif faces are not as legible as roman faces, they are widely used in advertising composition and, in some cases, for text. Lowercase letters are easier

EIGHT POINT BASKERVILLE AND ITALIC. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two *considerations of type-selection, readabili-*

EIGHT POINT BODONI BOOK AND ITALIC. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two considerations of type-*selection, readability and economy of space.*

Eight Point Bodoni Bold and Italic. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add *"character" to those other two consid-*

Eight Point Cairo and Bold. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two considerations of type-**selection, readability and economy of**

EIGHT POINT CASLON AND ITALIC. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two considerations of type-*selection, readability and economy of space.*

EIGHT POINT CENTURY AND ITALIC. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add *"character" to those other two consid-*

EIGHT POINT CLOISTER AND ITALIC. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or busineess-like, modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two considerations of type-selection, readability and *economy of space. As a typographer you will*

EIGHT POINT GARAMOND AND ITALIC. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or business-like modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two considerations of type-*selection, readability and economy of space.*

Eight **Point Vogue and** Vogue Bold. Type does more than provide the letters to spell the words that make a message. The feel of the message is conveyed by the type face itself, properly used. Whether the tone is to be warm or brisk, friendly or business-like, modern or old-fashioned, there is a type to say it. Therefore, add "character" to those other two considerations of type-selection, **readability and economy of space. As a**

Figure 15–11.—Samples of type faces commonly used as body type.

to read than masses of capitals or small capitals in blocks of text. Figure 15–11 shows some of the body type faces in common use.

The size of type also affects legibility. Most 8-point type faces are less legible than 10- or 12-point type. Ten-point type is large enough for comfortable reading, yet small enough to allow for a reasonable number of words to a page. That is why it is chosen as a body type for textbooks such as this. Twelve- and 14-point type faces are considered to be the most legible of all. For this reason, they are generally used for children's books and for some Navy publications which must be read under adverse conditions.

The length of the type line and the leading—that is, the spacing between the lines—also affect legibility. The length of the line used in body composition depends on the size and style of the type and the amount of leading between the lines. As a general rule, the pica length of a line should not be more than twice the point size of the type when the copy is set solid, plus 1 or 2 picas for each point that the copy is leaded.

A reader does not see each letter in a line. He sees in terms of words and combinations of words. Too much leading between lines makes the type less legible. Leading should be used to achieve tone and legibility, not to space out the type to fit the page. The job should be uniformly leaded throughout, since uneven spacing spoils its appearance.

The well designed page is one that contains a gray mass of type framed with white space. (See fig. 15–12.) Narrow margins cause pages to appear black and crowded and make them difficult to read. In fine bookwork, printers often divide the page half and half between text and marginal space, but this is impractical in most publications.

When you do layouts for a book or magazine, always consider facing pages as a single unit. Facing pages are called a SPREAD or a DOUBLE SPREAD. When the book is opened, the combined width of the white space between the two pages should be roughly equal to that of either of the outside margins. More margin should be left at the bottom of the page

than at the top or sides. Since the visual center of the page is above the actual center, the gray tone of type on a page of text looks best when it is centered on the visual center, rather than on the actual center.

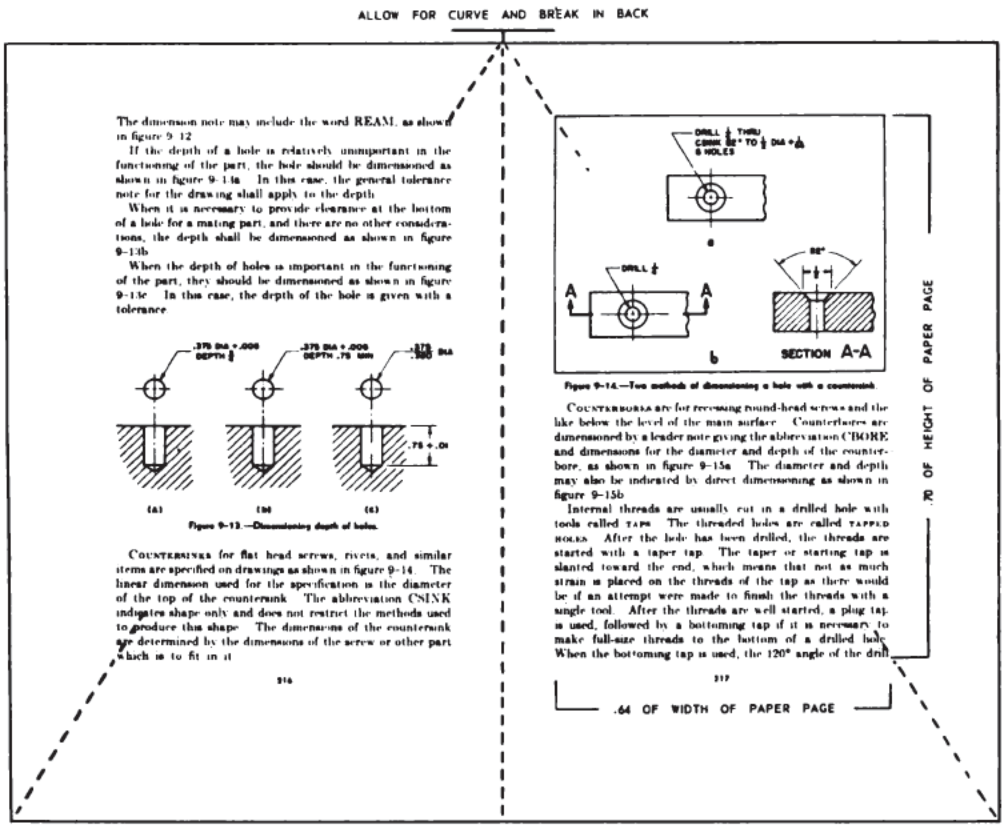


Figure 15–12.—Method of determining margins for a book.

Copy Fitting

When you have a layout to do, you may work directly with a writer and an illustrator, or you may be told the purpose of the layout, the general context of the copy to be included in it, and asked to produce ideas for both illustrations and display copy. At other times, you will be given manuscript copy and possibly even illustrations or photographs and asked to produce a layout incorporating these.

Photographs and illustrations may be scaled and cropped to fit a space. In order to determine the space that manuscript will fill when it is set in type, you must CAST the copy. There are several methods of casting or copy fitting. Some

of these, such as the words-per-square-inch method, are rather inaccurate and should be used only for rough calculations where accurate copy fitting is not necessary.

The following table will give you the approximate number of words per square inch for different sizes of type.

Size of type	Words per sq. in.	
	Solid	2 pt. leaded
6 pt.	47	34
8 pt.	32	23
10 pt.	21	16
12 pt.	14	11
14 pt.	11	7
18 pt.	7	5

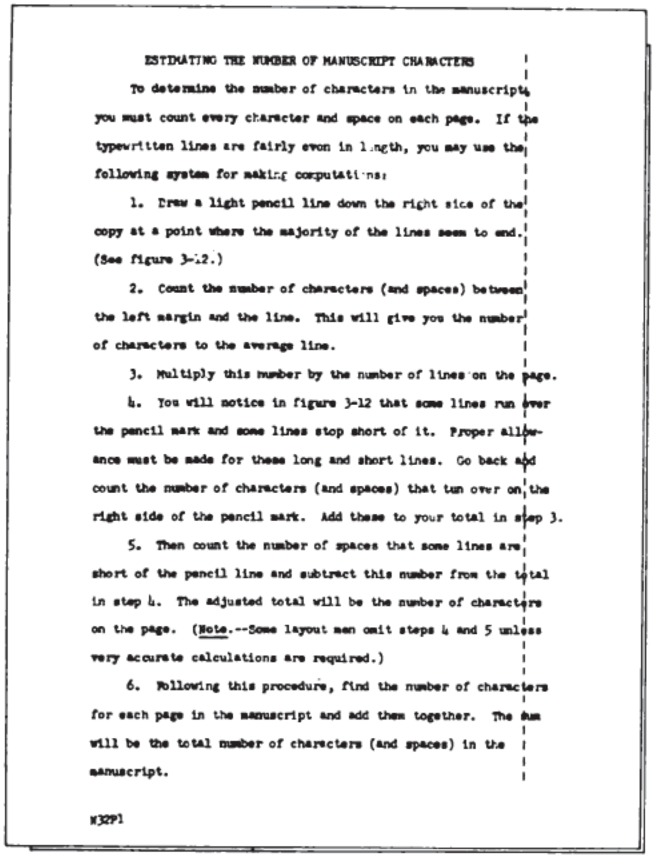
You can roughly estimate 250 words to one page of manuscript copy. Suppose you have 750 words of copy to be set in 10 point solid. If you divide 750 by 21, the number of words to the square inch for that size of type, you will find that the copy will require approximately 36 square inches of space. You can allow 4 inches by 9 inches or 3 inches by 12 inches, or any other combination of width and depth that will make up the 36 square inches on your layout. You can also use this table to find the number of words that will fit in a given space and have copy written to fit.

A more accurate method of copy fitting is known as the character-count method. To use the character-count method, you must first determine the number of characters in the copy. Figure 15–13 shows a quick way to count the characters and spaces in a typewritten manuscript.

After you have found the total number of characters in the manuscript, you must divide it by the average number of characters that will fit into a line set in the style and size of type that you wish to use. This will give you the number of lines that your copy will fill. You can find the average number of characters to the typeset line by counting the characters in a line set to the proper width in the size

and style of type that you are going to use. If you count the characters in several lines and average the totals, you will get a more accurate count.

Then take a ruler and measure the typeset copy to see how many lines will go in an inch. Divide this number



ESTIMATING THE NUMBER OF MANUSCRIPT CHARACTERS

To determine the number of characters in the manuscript, you must count every character and space on each page. If the typewritten lines are fairly even in length, you may use the following system for making computations:

1. Draw a light pencil line down the right side of the copy at a point where the majority of the lines seem to end. (See figure 3-12.)

2. Count the number of characters (and spaces) between the left margin and the line. This will give you the number of characters to the average line.

3. Multiply this number by the number of lines on the page.

4. You will notice in figure 3-12 that some lines run over the pencil mark and some lines stop short of it. Proper allowance must be made for these long and short lines. Go back and count the number of characters (and spaces) that tun over on the right side of the pencil mark. Add these to your total in step 3.

5. Then count the number of spaces that some lines are short of the pencil line and subtract this number from the total in step 4. The adjusted total will be the number of characters on the page. (Note.--Some layout men omit steps 4 and 5 unless very accurate calculations are required.)

6. Following this procedure, find the number of characters for each page in the manuscript and add them together. The sum will be the total number of characters (and spaces) in the manuscript.

N32P1

Figure 15–13.—Method for counting characters and spaces in a manuscript.

into the number of lines that the copy will fill, and you will find the total length of your manuscript in inches. But you must also make allowance for headings and illustrations. And in some books, you must take into consideration the blank space above chapter headings and the blank space at the ends of chapters.

Marking and Keying Copy

After you have drawn up a complete and accurate layout; your next step is to write in instructions for the printer.

Both art and manuscript copy should be keyed to the layout. Other instructions may be written on the layout, but more often they are written on the manuscript. You should indicate the size and kind of type, the leading desired, and the dimensions of type areas. You should check to be sure that the art copy is marked to reduce to the size shown on the layout and then key the art copy to the layout with number or letter, as shown in figure 15–14. The manuscript copy may also be keyed to the layout, as shown in figure 15–15.

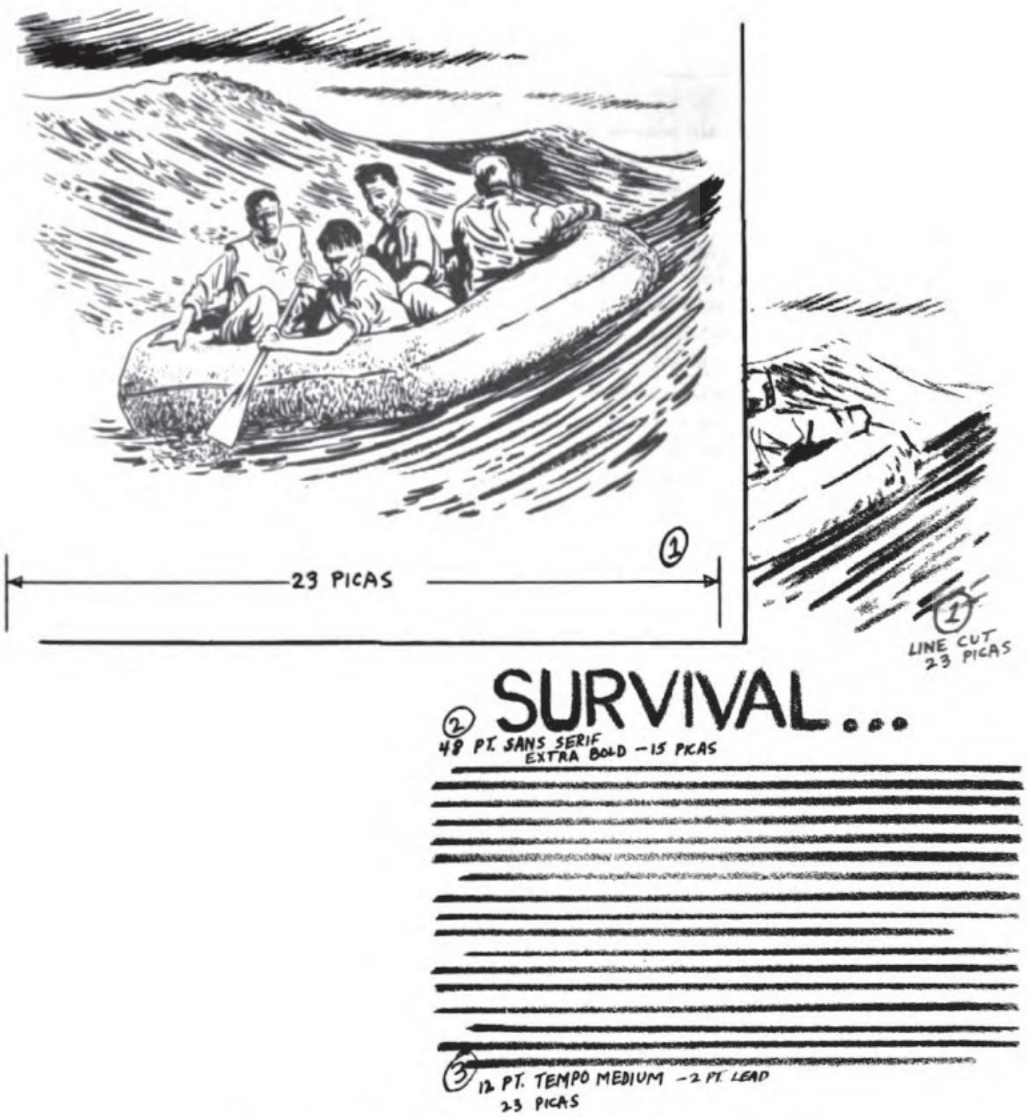
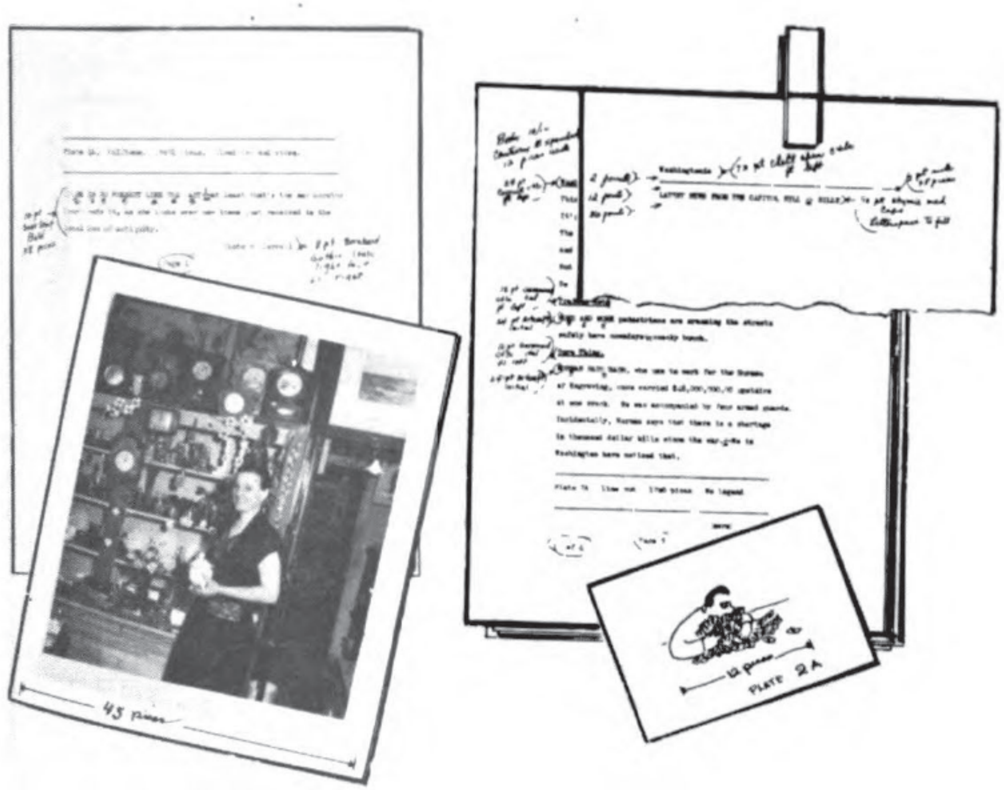


Figure 15–14.—Art copy keyed to a layout.



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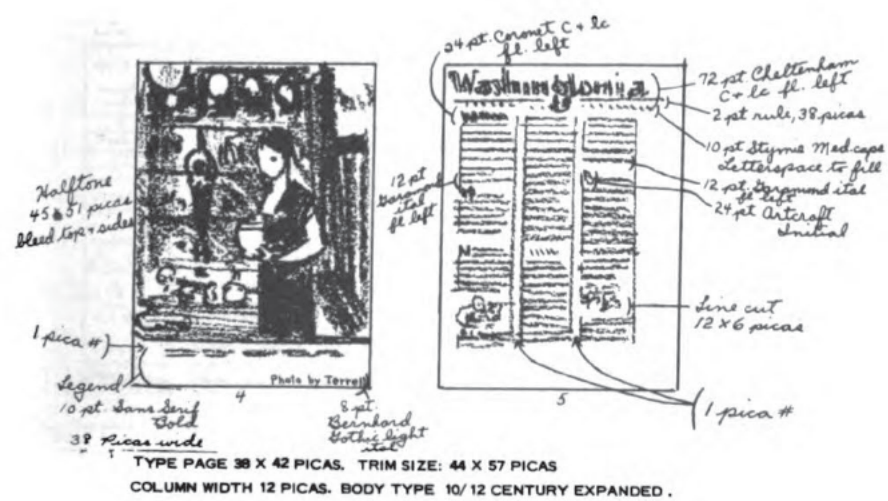
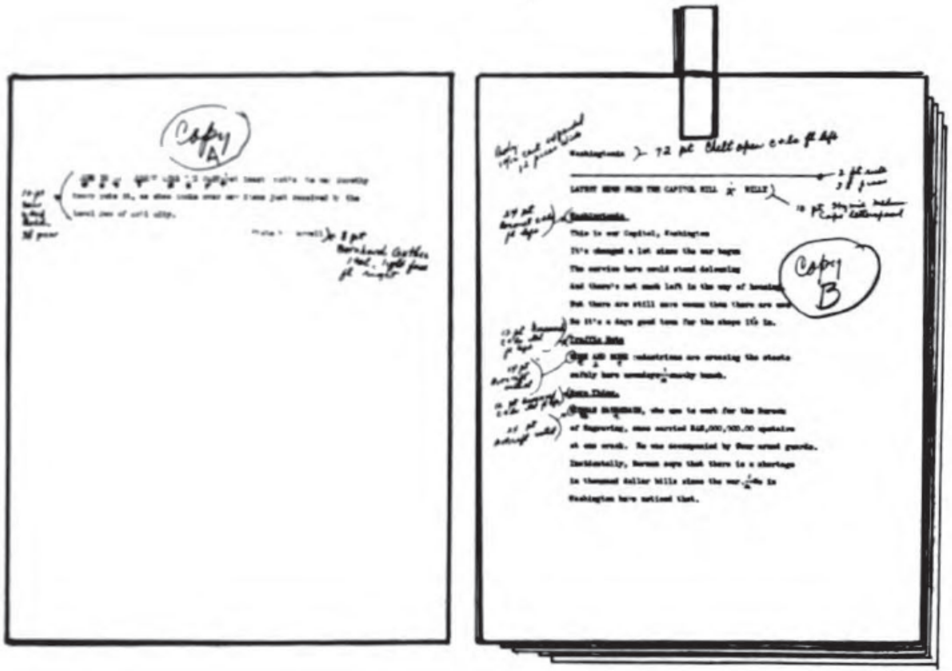


Two-page layout.

Figure 15–15.—Manuscript copy marked for type and keyed to layout.



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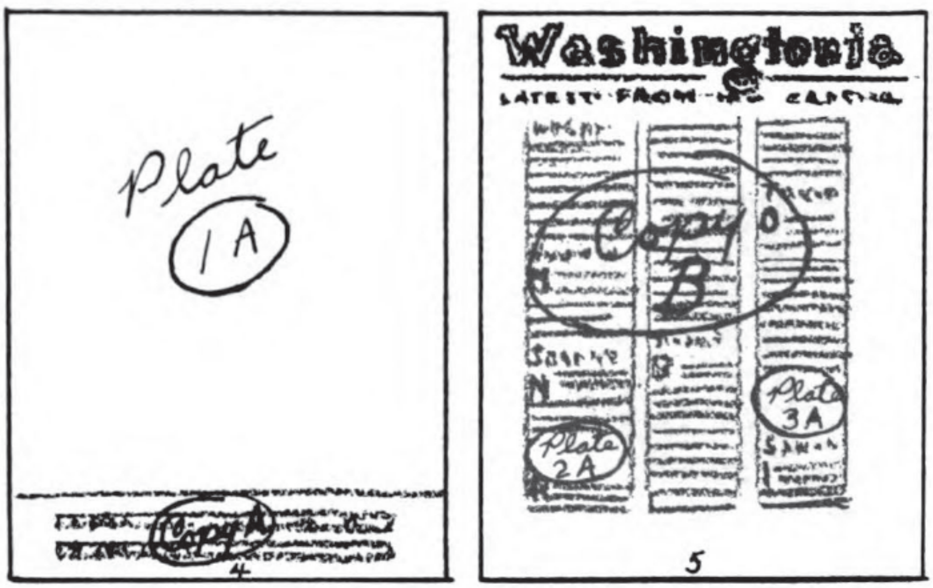


Two-page layout.

Figure 15–15.—Manuscript copy marked for type and keyed to layout—Con.

ILLUSTRATION

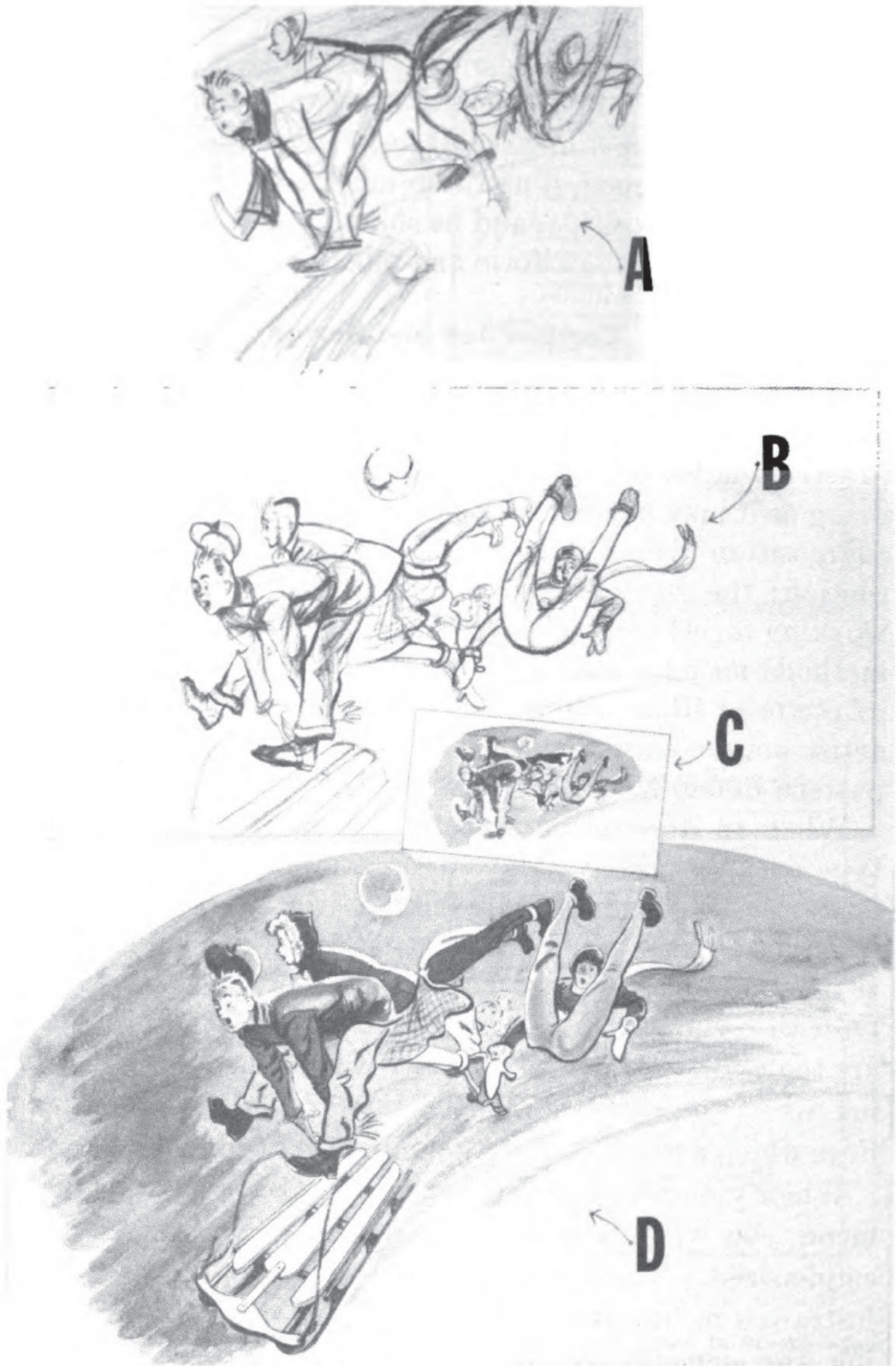
An illustration may be purely decorative or it may be the graphic means of conveying a message. It may consist of a realistic three-dimensional scene or an abstract pattern. In any case, a good illustrator must be a master of both design and composition, and he should know how to use line, tone, and color to show form and mood.

Composition and Design

The COMPOSITION of an illustration means the arrangement of the various elements in the illustration, or the plan of the illustration. The word DESIGN may be used to mean the same thing or it may be used to mean a decorative element. Good composition gives the viewer a sense of harmony and completion; the story is all there; the different elements are working together toward a common end. Actually the same methods may be used as those discussed under layout, but in pictorial illustrations, a third dimension is added. The artist must compose not only a surface pattern but also a pattern in depth.

When an illustration is to be combined with lettering or type as in a poster, a layout or comprehensive is usually made. This should be drawn the size the poster will be when it is printed, but the artist may render the illustration as much as twice this size, keeping in mind the effect that the reduction will have. If the lines of the enlarged rendering are too close together, the space between them may fill with ink when the illustration is printed. On the other hand, lines which are not strong enough will fade out.

When you compose an illustration, first decide what elements you will use and the order in which these are to be emphasized. Then work out the surface pattern of the illustration in line and tone so that the proportions are pleasing, the elements balance each other, and there is contrast and direction. At the same time, keep in mind that the illustration must hang together as a unit.



After drawing by Vance Locke

Figure 15–16.—Different stages of one illustration.

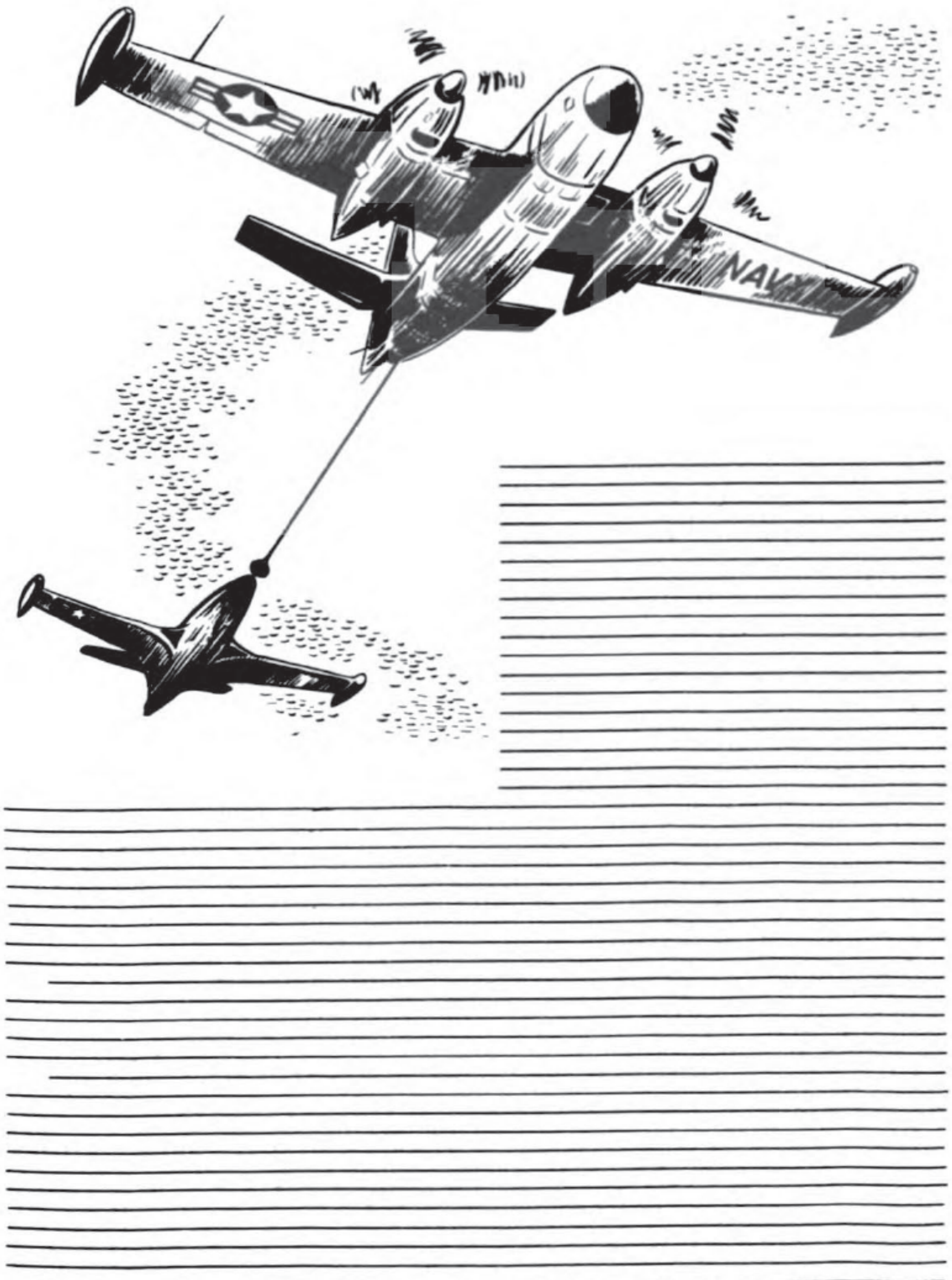


Figure 15–17.—The page should be balanced, whether the illustration is balanced or not.

In order to do all this, you may make several preliminary sketches. (See fig. 15–16.) When you have decided on the elements and their general relation to each other, use tracing paper to work out the pattern of the lines, the tones, and the colors if you are using color.

The lines of an illustration serve to direct the eye of the viewer. They are the framework of the illustration. They can be used to point to the most important element. They may repeat for emphasis, alternate, or contrast. No less important than the obvious lines are the implied lines—unfinished lines that are finished by the mind of the observer or lines indicated by the edge of a form here and a change of tone or color somewhere else.

Tones, and colors when they are used, provide the most obvious contrasts. As in layout, they must be balanced if the illustration is to appear balanced. However, when the illustration is to be used as one element in a layout, it does not have to be balanced in itself, provided the page or spread is balanced as a whole. (See fig. 15–17.)

Strong contrasts in tone usually make an illustration's impact stronger. Also tone can be used to emphasize important elements. Very strong contrast should be reserved for the most dramatic elements. When elements in the background are rendered in gray tones and the darkest tones, as well as the whites, are used on foreground figures, they will stand out dramatically from the background. (See fig. 15–18.)

Like contrasting tones, contrasting textures can be used to add to the dramatic effect and to the naturalism. Different materials, such as metal, glass, cloth, and hair, differ radically in their surface texture. If you observe these differences carefully, you can learn to suggest the texture without cluttering up your illustration with too many details. Often a detail of texture on a lighted portion of an object is enough to suggest the texture of the whole. (See fig. 15–19.)

Form is of first importance in an illustration. In a layout, form or shape is limited to a certain degree by the physical

After drawing by John Cullen Murphy

Figure 15–18.—Use of blacks and whites for foreground figures.

Figure 15–19.—A suggestion of texture is often enough to add to the dramatic impact of the illustration.

facts of printing makeup, type size, and copy length. But in an illustration, no such limitations are imposed, except that in letterpress printing the illustration should not be planned so that it projects into the typeset areas. Otherwise an illustrator may utilize the utmost in contrast in form. He may, by differences in the sizes of forms alone, suggest great depth or distance, as illustrated in figure 15–20, or he may use contrasting shapes for their dramatic impact alone.

In rendering natural forms, remember that more details can be seen in close objects than in those in the distance. To help produce an illusion of reality, simplify more distant forms. Also notice that when you look directly at an ob-

Figure 15–20.—Contrasts in form to indicate depth or distance.

ject, you see it in greater detail than the objects to each side of it. This fact can be used to focus attention on the most important or dramatic forms in an illustration. When a form is rendered in detail and the forms surrounding it are suggested rather than finished, it will stand out and attract the eye of the viewer.

Anatomy

The first step in learning to draw the human figure consists of learning to visualize the figure as a solid, a thing of muscles and flesh on a framework of inflexible bone. The bones can be bent only at the joints, and most joints will bend only in one direction. Study the skeleton shown in figure 15–21 carefully. Notice that the bones have individual

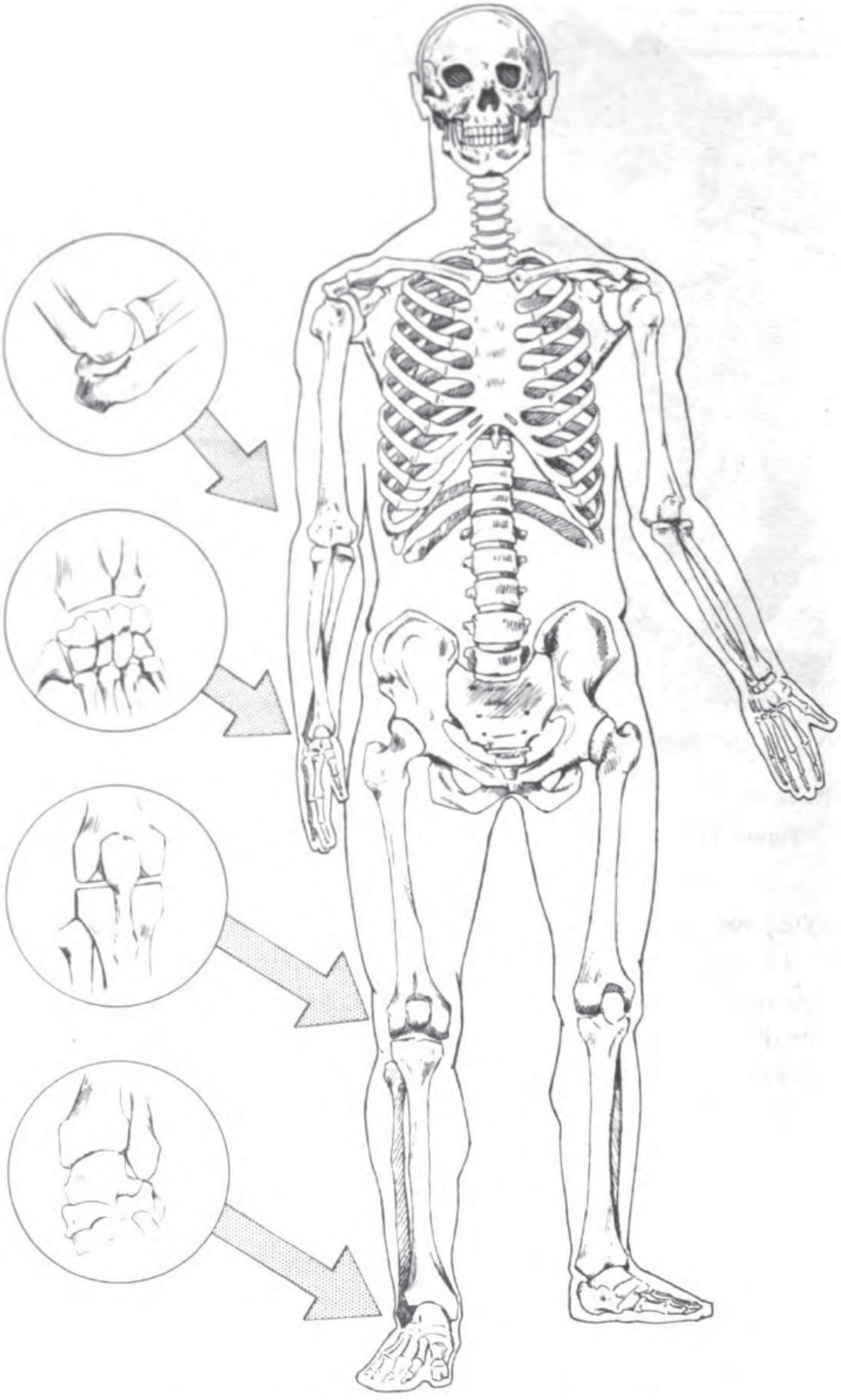


Figure 15–21.—View of a human skeleton.

shapes. Notice particularly the shapes at the joints of the knees, ankles, elbows, and wrists.

Now look at the figure in 15–22. Here the figure on the left is represented in the same positions as in figure 15–21, but in this case, the major muscles are drawn superimposed on the skeleton. In figure 15–23, a nude figure is shown in the same positions.

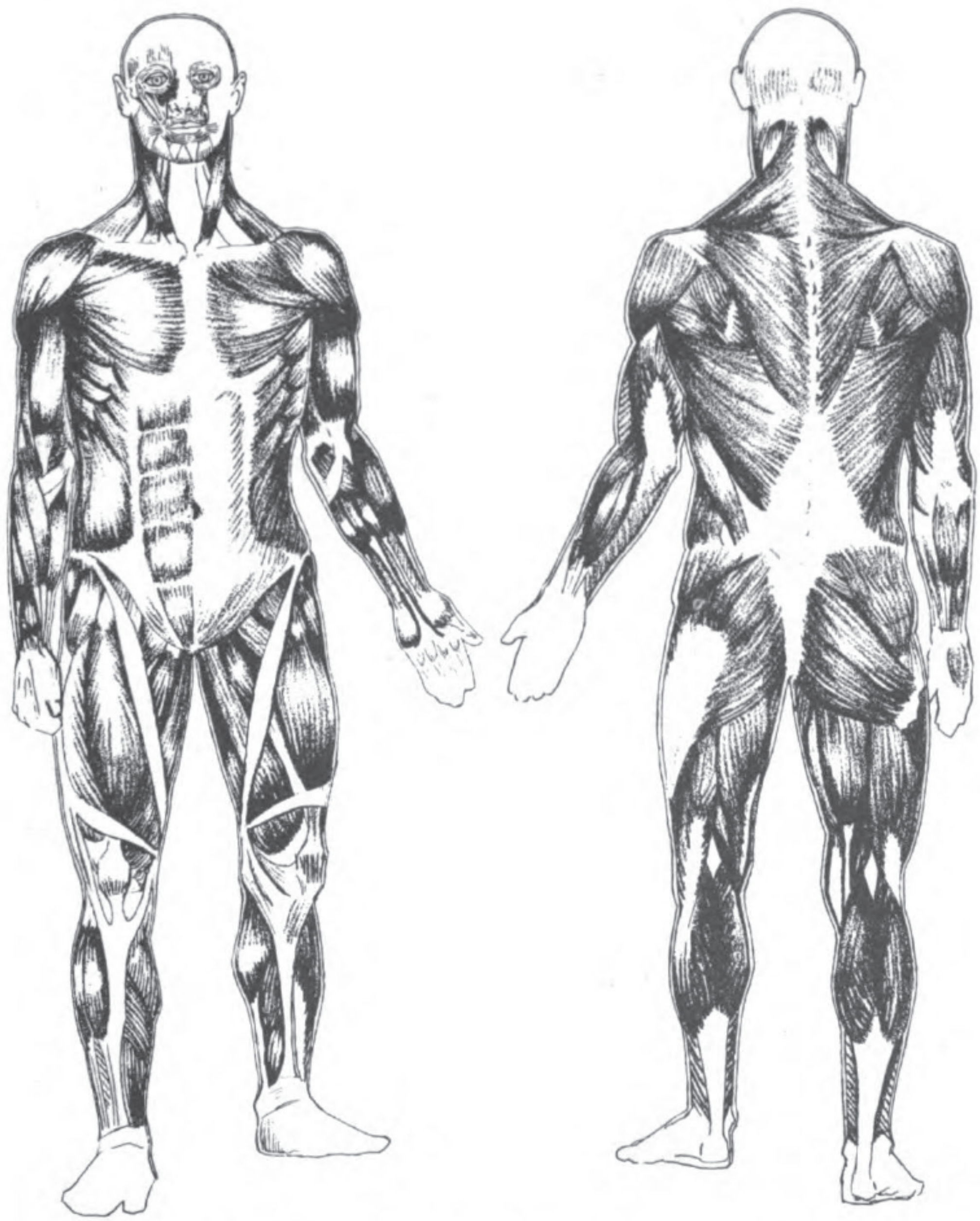


Figure 15–22.—Views of human figures showing major muscles.

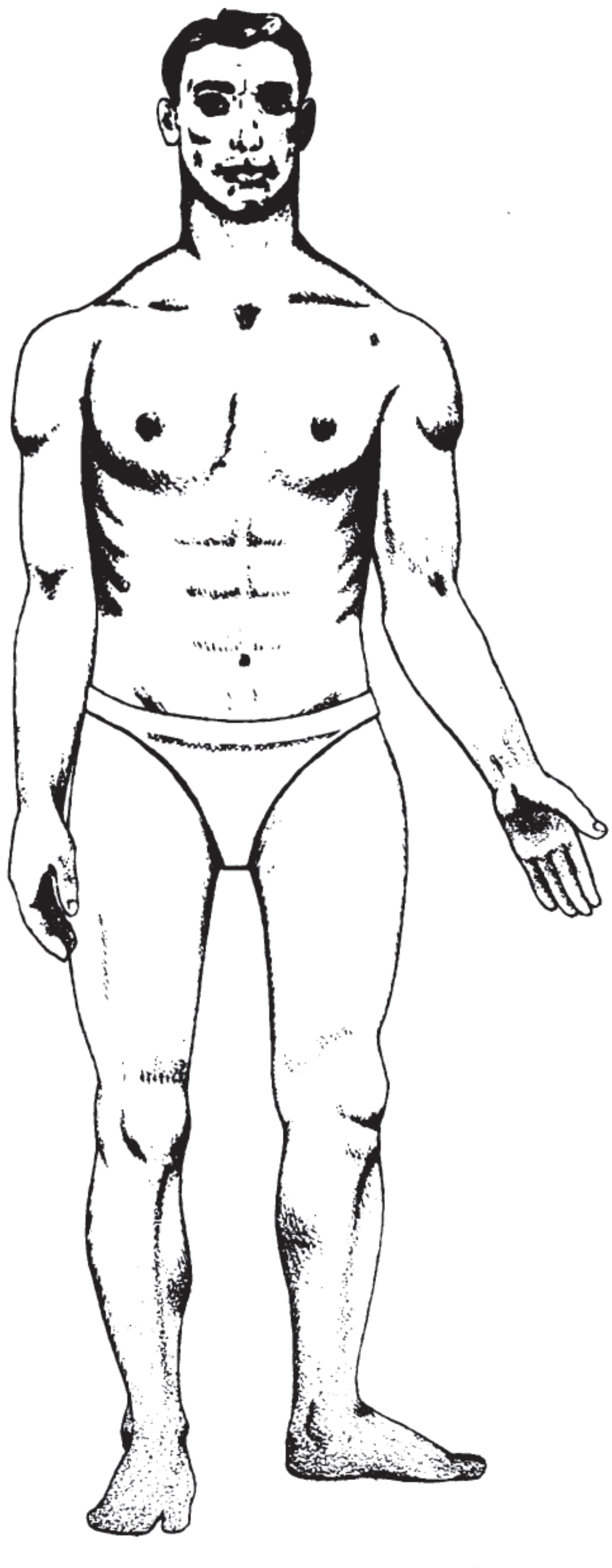


Figure 15-23.—View of human figure.

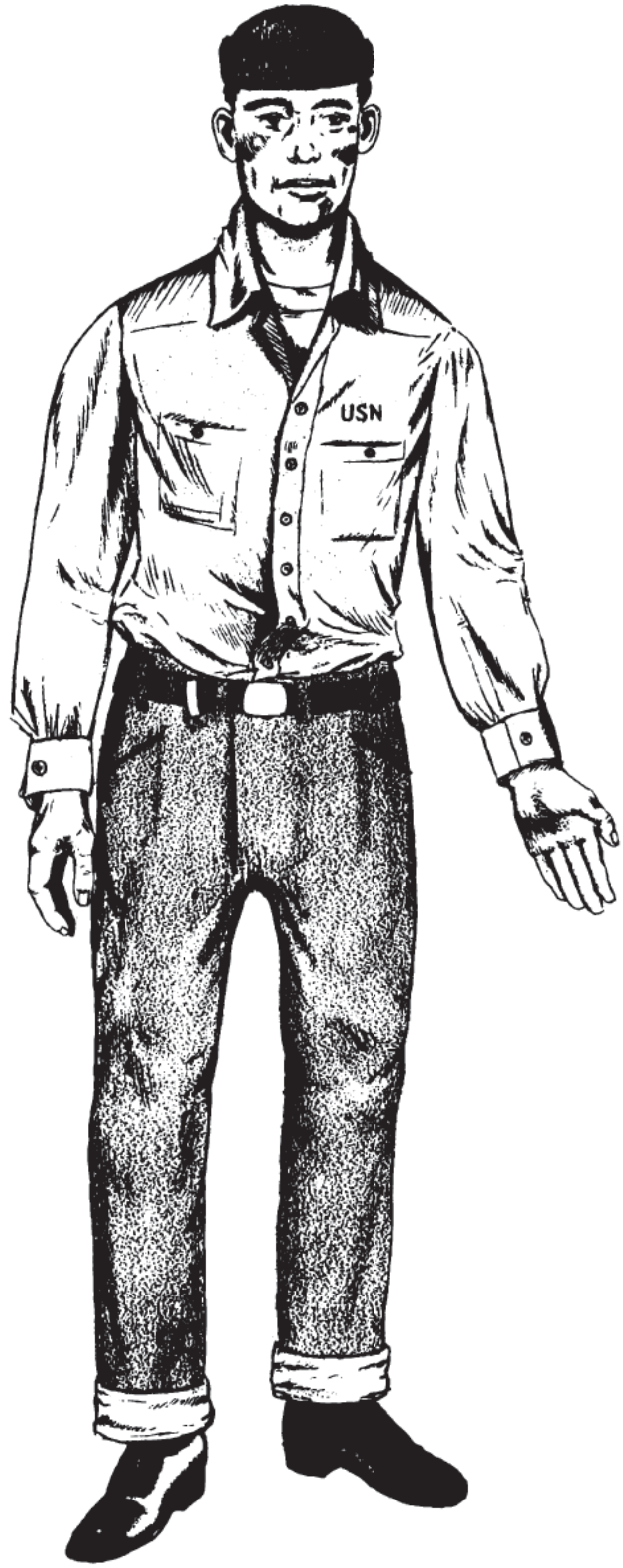


Figure 15–24.—Clothed figure.

When the figure is clothed, the folds of the clothing must still conform to the shape of skeleton and muscles underneath. (See fig. 15–24.) Make a practice of studying the way the folds fall in the clothing of the people around you. Notice that there are two types of folds. Some folds fall from points where the body supports the cloth. Another type of fold is the cross fold formed in places where the body bends and the cloth is rumpled instead of pulled tight and straight.

The female figure has the same general proportions as the male figure, the same bones in the skeleton, the same muscles, but there are variations in the proportions of the parts. The bones are, in general, slighter, the shoulders not so wide, and the pelvis wider. (See fig. 15–25.) The muscles are less developed, and a layer of fat under the skin causes the figure to appear less angular and more softly rounded. (See fig. 15–26.)

Heads, both male and female, may be classified as square, round, or oval, but actually all heads are variations of the oval or ovoid shape. Knowledge of the bony structure, the disposition of cartilage, as in the nose, and the muscles is especially important if you are to do a successful rendering of a head. Figure 15–28 shows two skulls and several finished studies of heads. Note the cheekbone in the skulls and its effect in the finished heads.

The eyes are large, round balls set in the sockets of the skull and with both a top and a bottom lid. The dark pupil is surrounded by an iris, and this in turn by a creamy or gray white coating on the eyeball. Notice the construction of the eyelids in figure 15–28. The expression of the eyes can be sharpened by the addition of highlights on the pupil or iris. In orientals, the eye is constructed the same way, but the outside corners of the eyelids are caught up so that the eye opening slants.

The nose is constructed of cartilage extending out from the bone of the skull. The nose in figure 15–29A has been drawn as if it were made up of a number of flat planes in

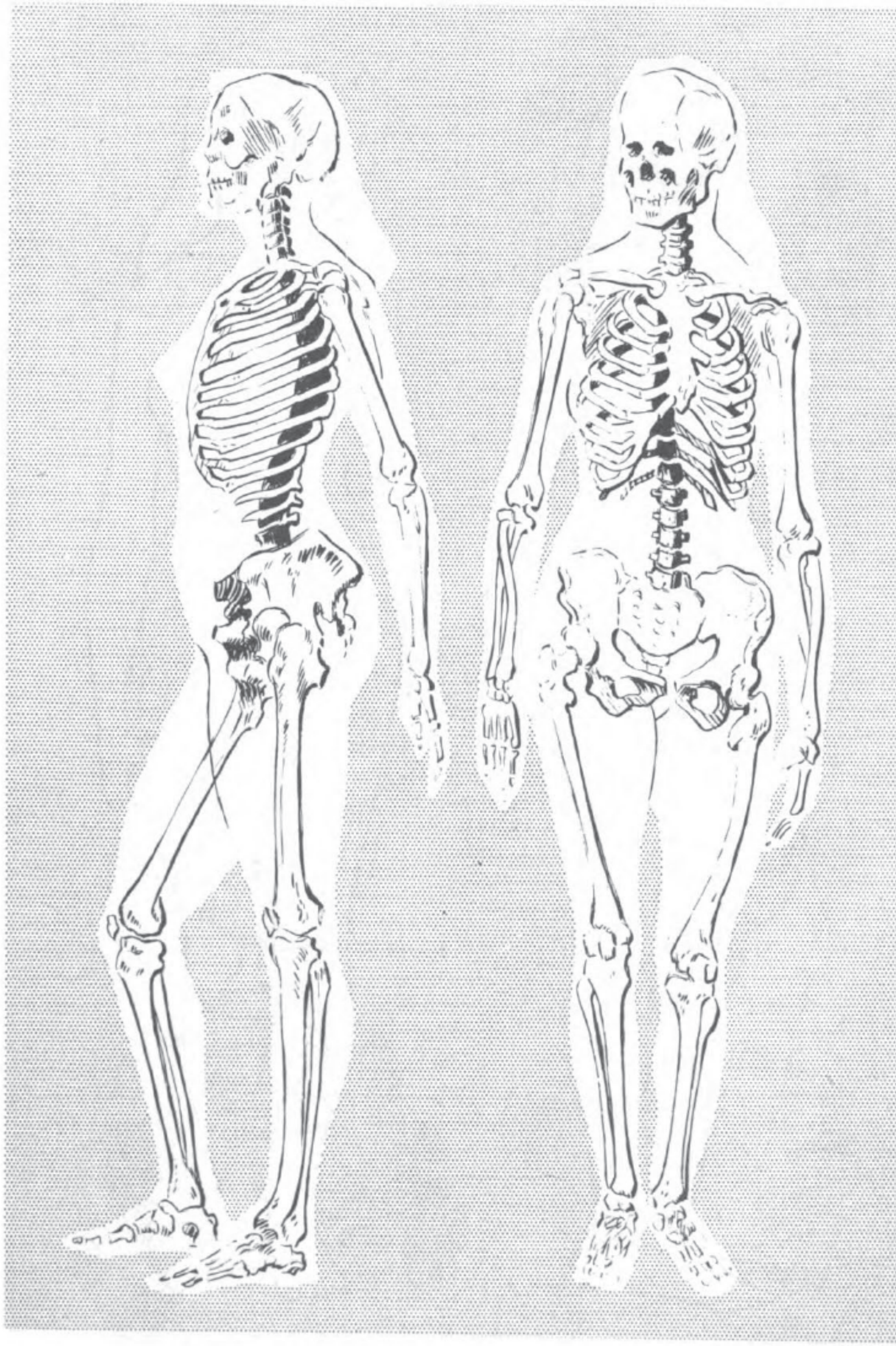


Figure 15–25.—Female skeleton in two positions.

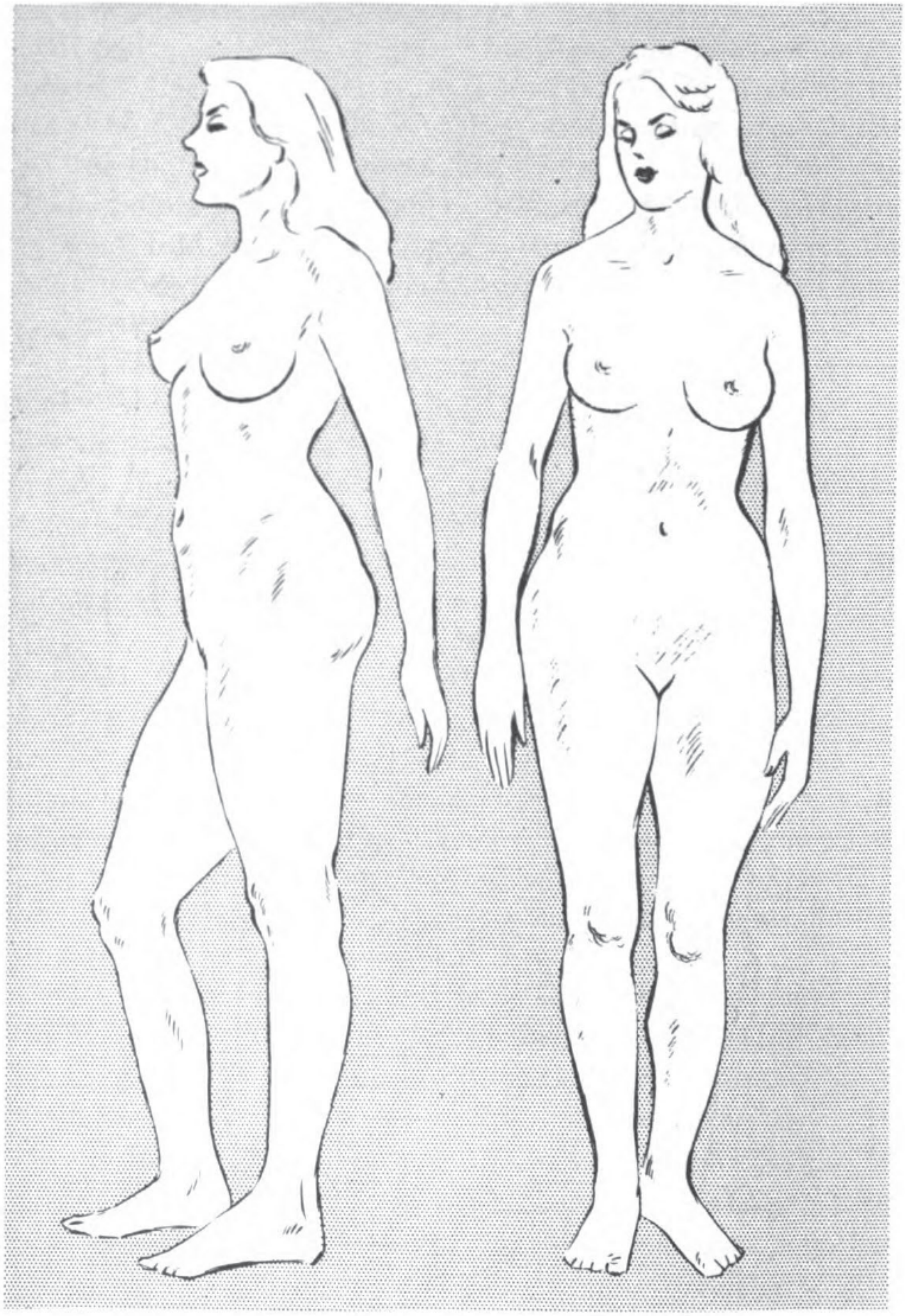
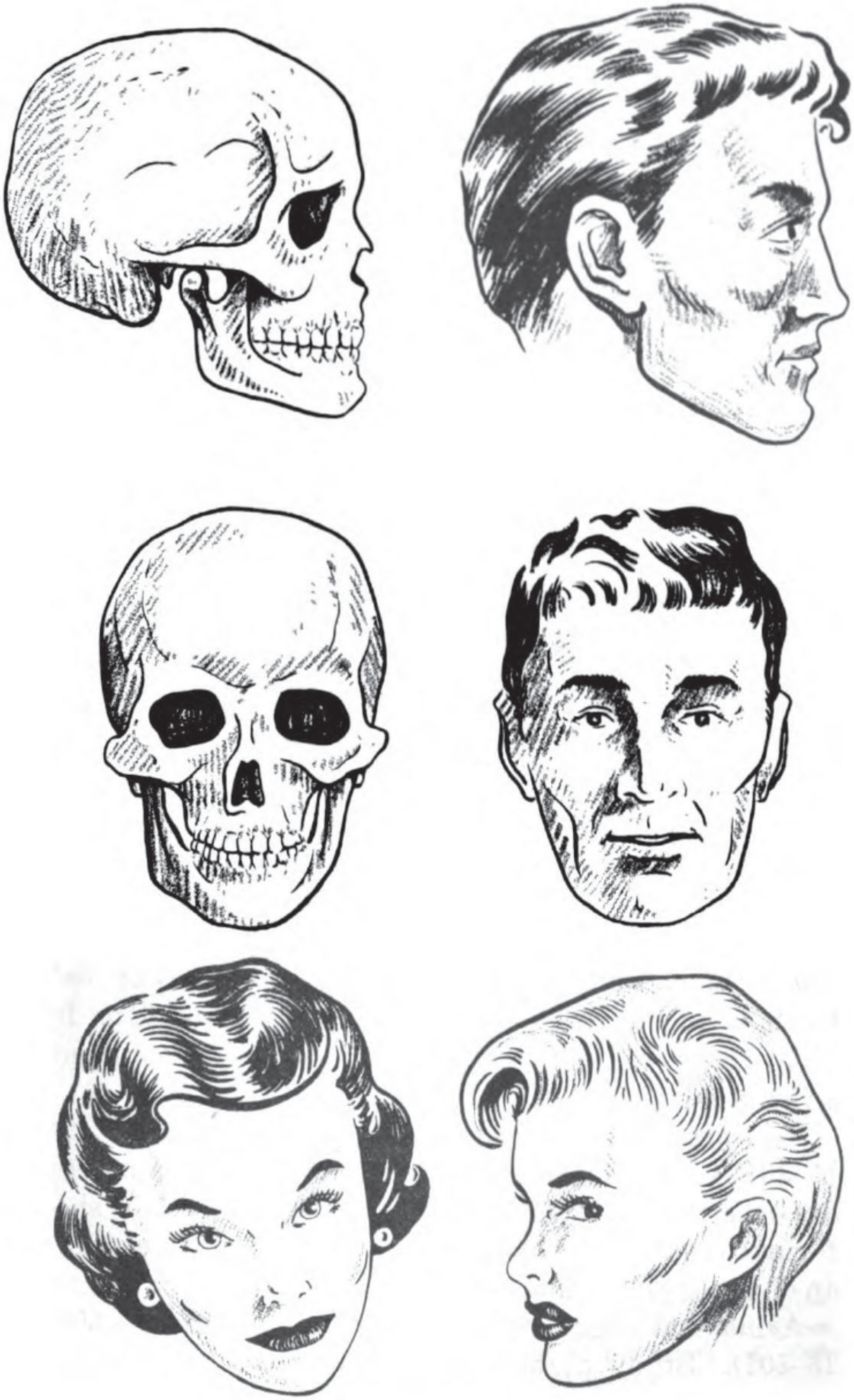


Figure 15–26.—Female figures.



Figures 15–27.—Studies of skulls and heads.

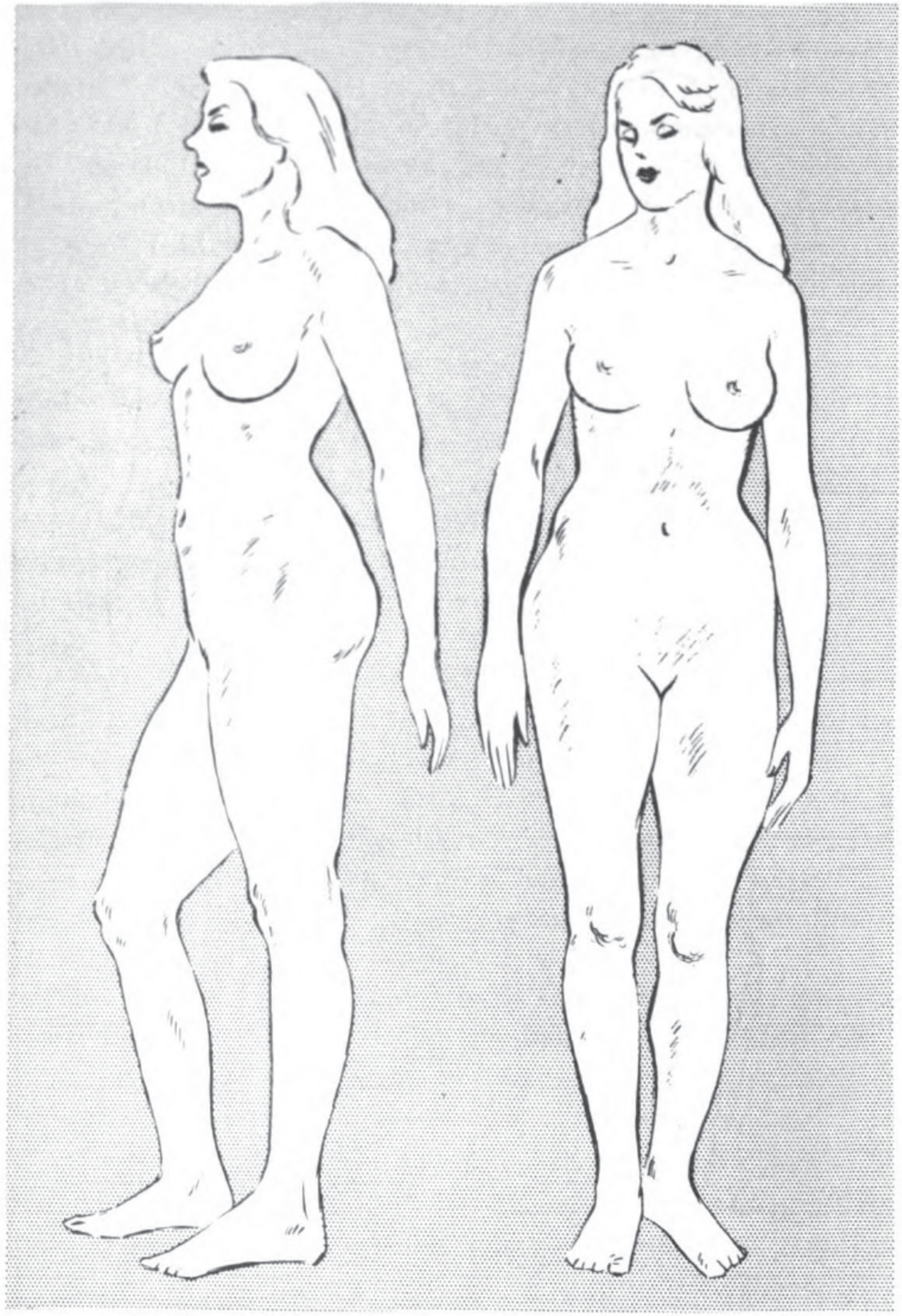
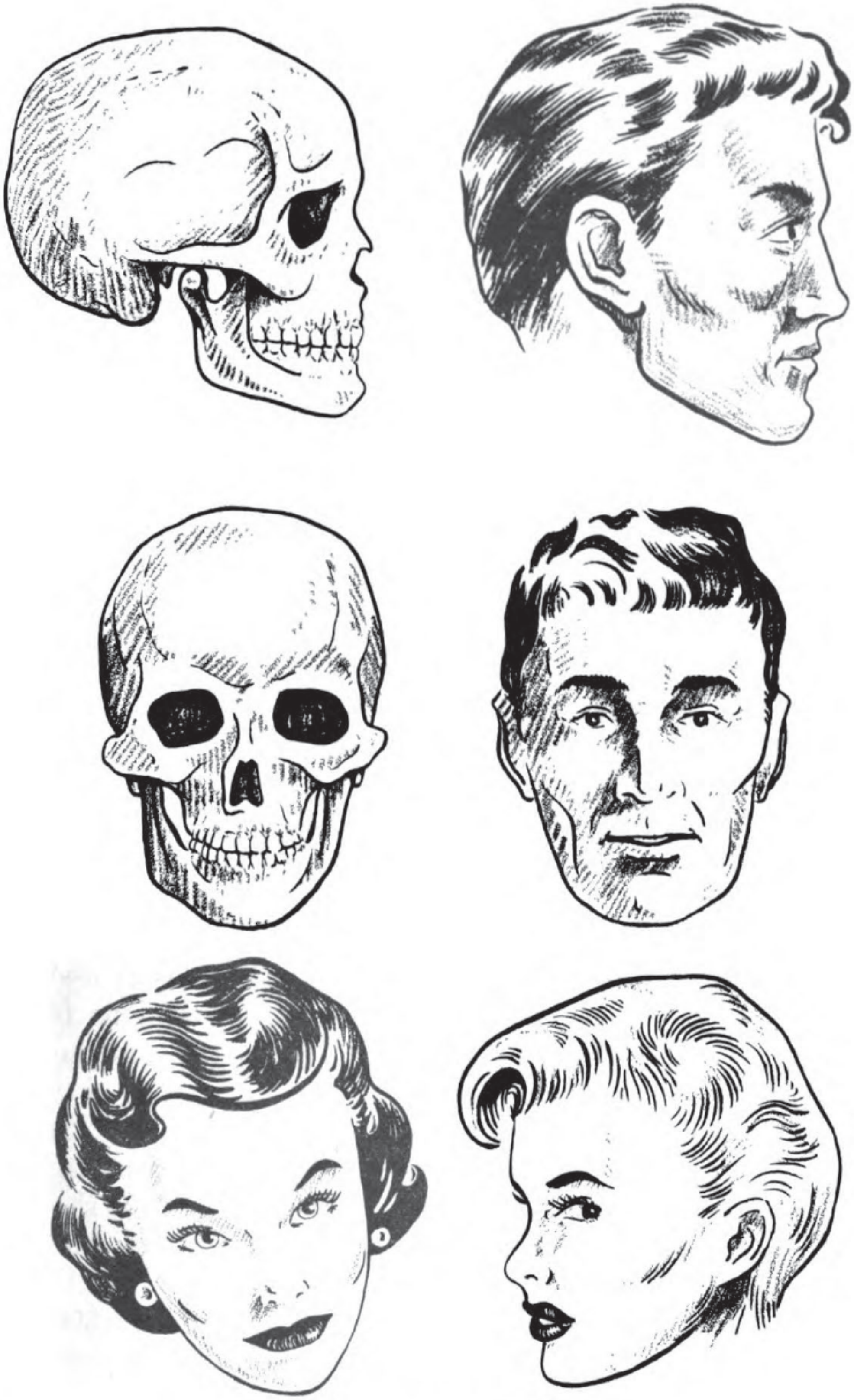


Figure 15–26.—Female figures.



Figures 15–27.—Studies of skulls and heads.

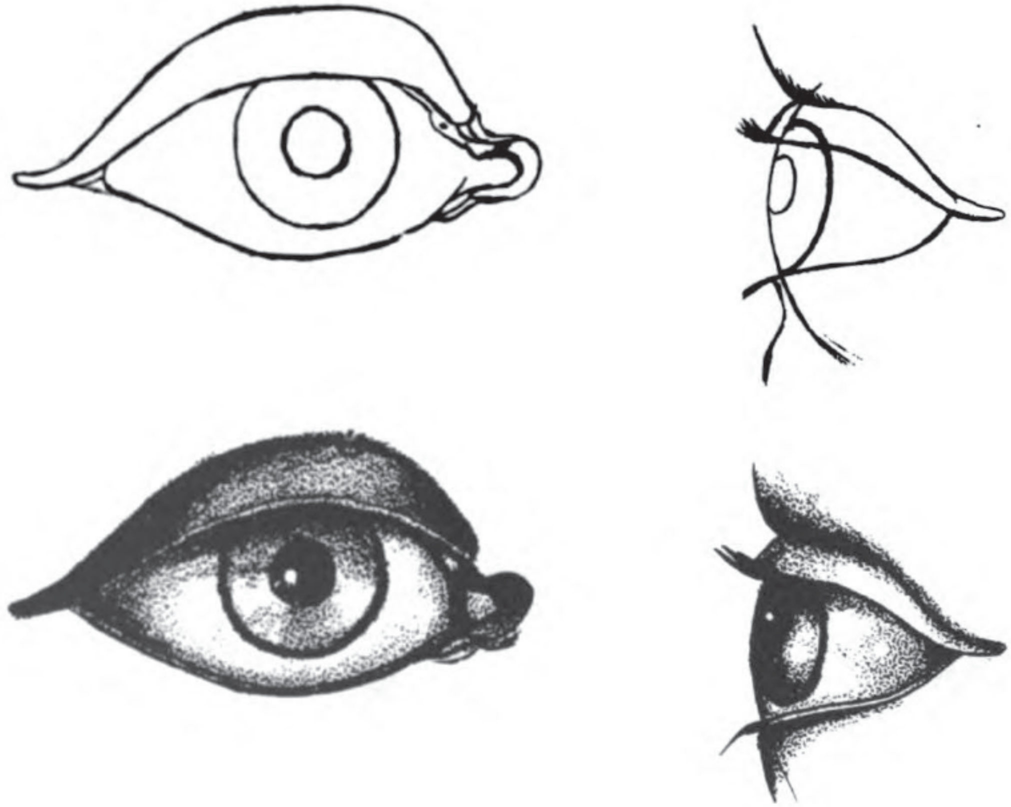


Figure 15–28.—Construction of the eye.

order to emphasize the construction. The same is true of the mouths shown in figure 15–29B. Figure 15–29C illustrates an ear with the same emphasis on the planes.

Hands are one of the most difficult things to draw well. Study your own hand and make a few sketches of it similar to those in figure 15–30A. Note how the tendons fan out from the wrist to the fingers and the thumb and how the wrist is formed.

Feet are also interesting but difficult to draw. (See fig. 15–30B.) After you have done some sketches of feet, try drawing them in shoes. Note how the shape of the shoe conforms to that of the foot, and the difference in shape between an old shoe and a new one.

Arms and legs are illustrated in figures 15–30C and 15–30D. Study these and then turn back to figures 15–21,

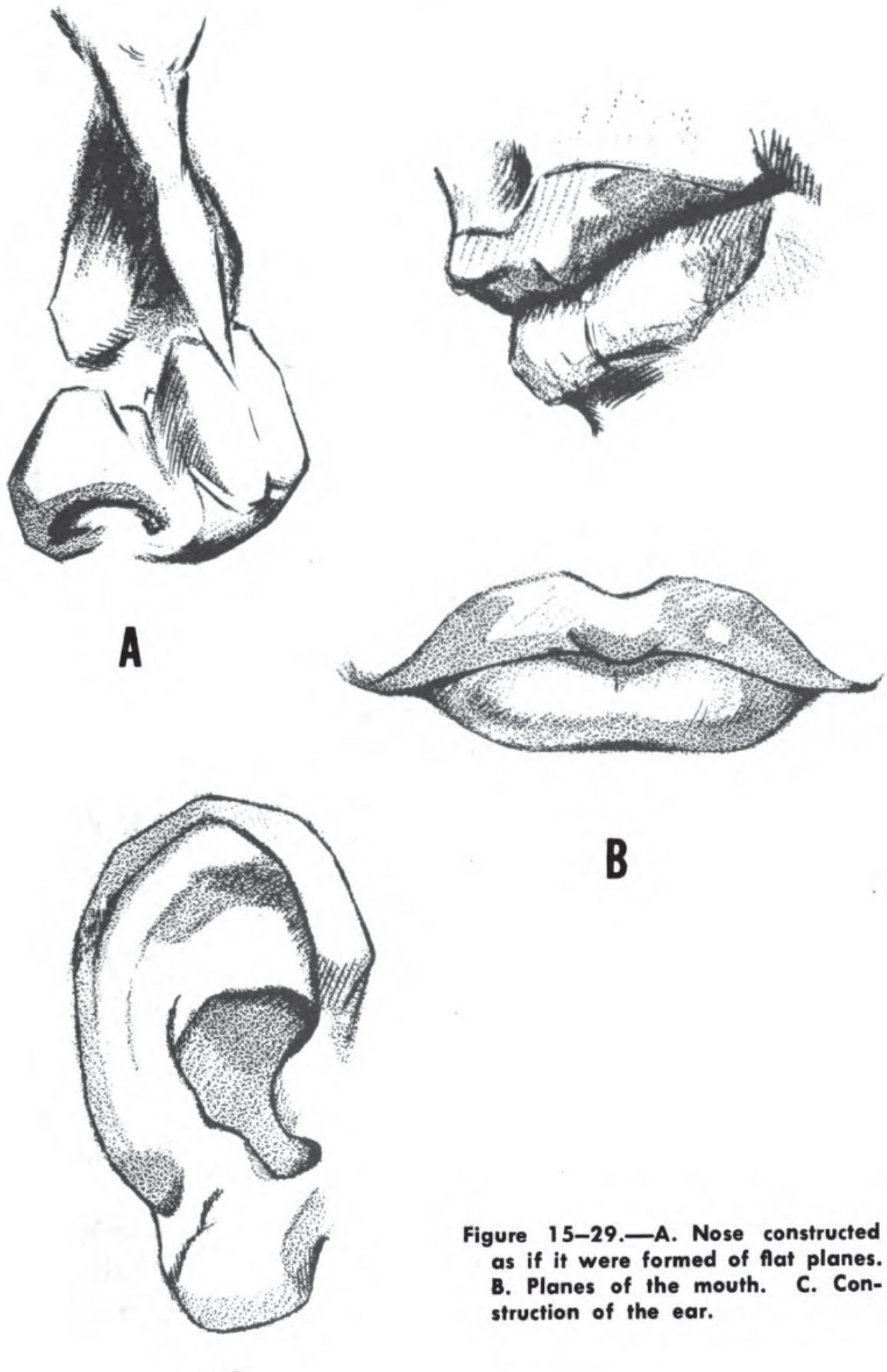


Figure 15–29.—A. Nose constructed as if it were formed of flat planes. B. Planes of the mouth. C. Construction of the ear.

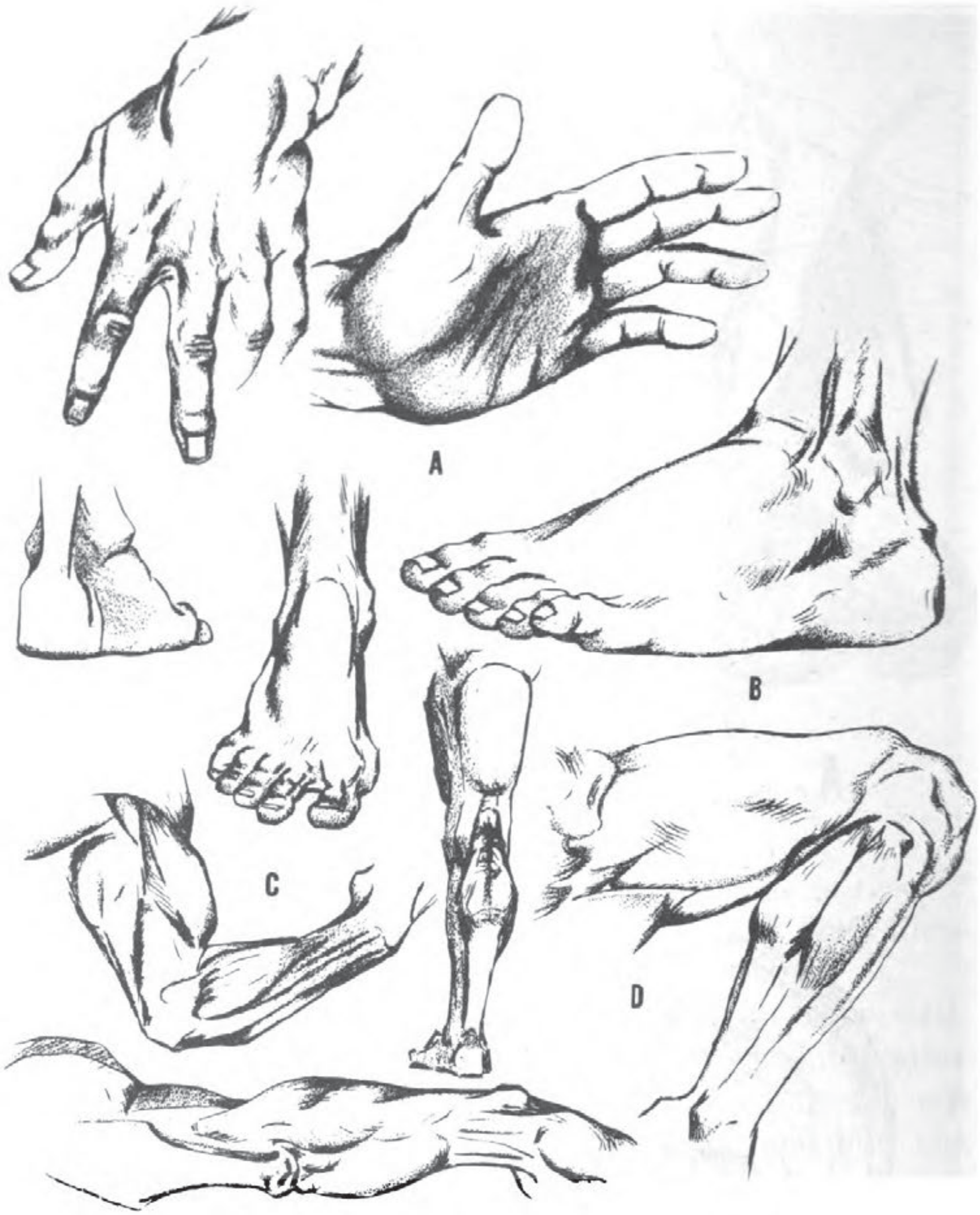


Figure 15–30.—Sketches of hands, feet, arms, and legs.

15–22, and 15–25, which show the bones and muscles of the arms and legs.

Once you have learned to think of human figures in terms of solid bones and muscles, you can apply the same thinking in drawing animal figures. The horse, dog, and cat in figure 15–31 were each drawn first with construction lines. The

Figure 15–31.—Horse, dog, and cat.

skeletons contain very much the same structures as that of man, and the muscles are generally the same. The chief skeletal difference consists of the modification of the limbs. The horse, for example, runs on what would be fingers and toes in man. He even has atrophied toes and fingers behind the hooves on his legs.

Cartoons

The difference between a cartoon and a straight illustration is that the illustration hints at the story which it accompanies, while the cartoon usually is the story itself. The cartoon, therefore, has to show something very definite and show it clearly. It must be, first of all, expressive. The cartoonist is free to exaggerate as much as he chooses, so long as he adds to the expressiveness of the cartoon with his exaggera-

After drawing by Jay N. Darling

Figure 15–32.—Sketch with free lines and a maximum of expressiveness.

tion. He also does well to eliminate as many of the non-essentials as possible.

You may start out to become a cartoonist by copying the styles of other artists, the funny sailor and the pretty girl, but if you have the makings of a good cartoonist, you will start before long to develop a style of your own which is based on real knowledge of what people look like and how they feel.

In order to be a good cartoonist, you must know anatomy, know the techniques of drawing, and be a shrewd observer of people. A cartoon may be a violent distortion of reality, but if it is a good cartoon, the distortion is there, not for distortion's sake alone, but in order to express most forcibly a real fact about real people or things.

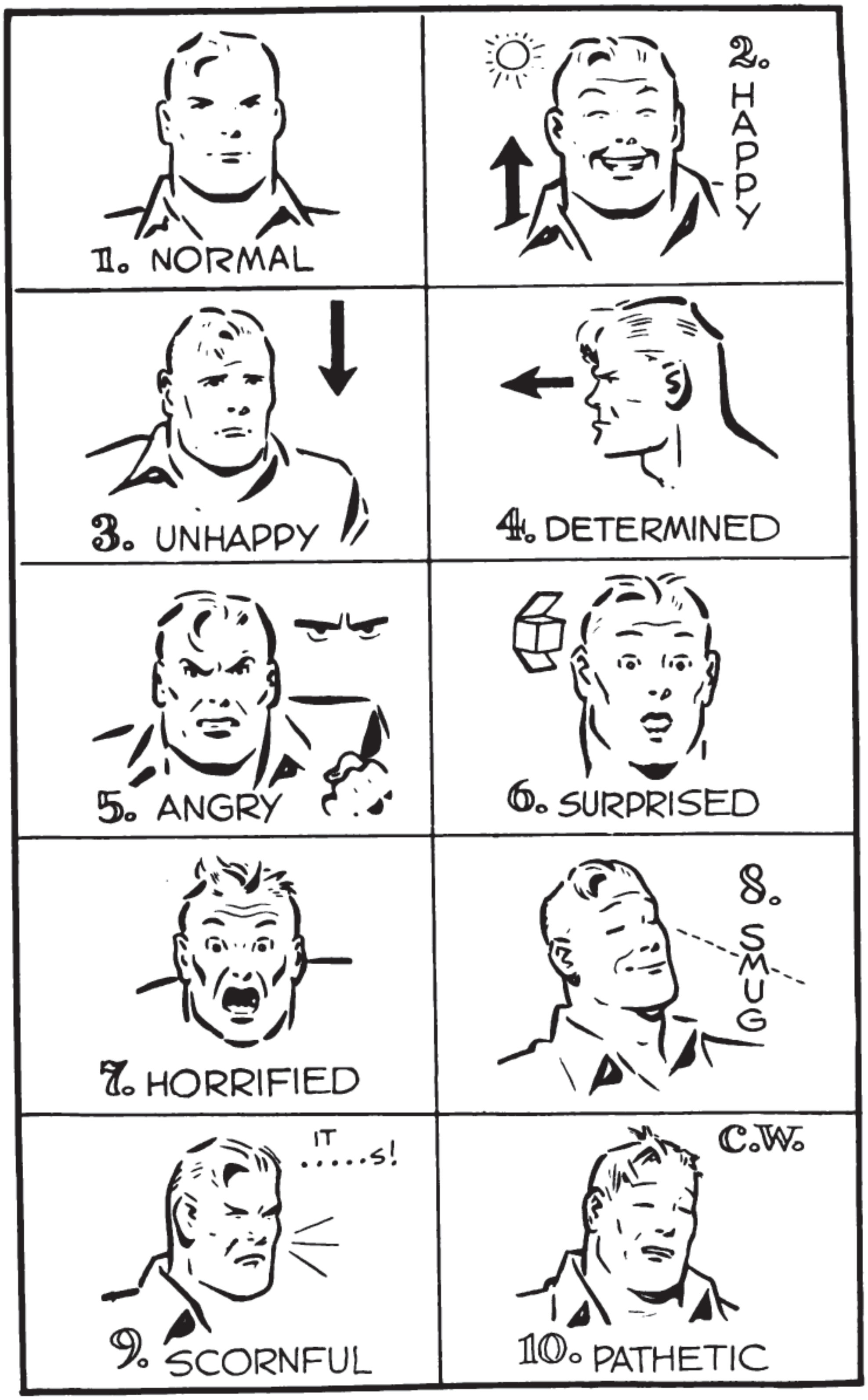
If you want to learn to draw cartoons which express real emotions or actions clearly, carry a sketch pad with you whenever you can and make on-the-spot sketches of the people you see. Try to draw them quickly and with as few lines as possible. At first the results will probably disappoint you, but keep at it until you can draw almost any pose you see with such facility that it is like writing. This will also help you develop a free and easy style of drawing. (See fig. 15–32.)

Expression

Cartooning becomes a fine art when the figure in the cartoon is drawn so as to express a distinct and complex personality. Start by learning to express single emotions. Remember that facial expression and the attitude of the body should be consistent.

Facial expression is produced by the movement of the movable parts of the face—the mouth and the muscles around it, the eyelids, eyebrows, even the wrinkling of nose or forehead. For example, in figure 15–33, a number of emotions are expressed simply by changing the shape or position of the mouth, eyes, and eyebrows.

When the face assumes a happy expression, the movable



Courtesy Coulton Waugh

Figure 15–33.—Facial expressions.

parts of the face are lifted. The corners of the mouth are pulled up and out. The cheek muscles are bunched by this action so that the lower lid of the eye is pushed up and the eye almost closed. The eyebrows are raised.

To make the face unhappy, the corners of the mouth are dropped. Notice that the lines of the eyebrows are lowered but are a little higher toward the bridge of the nose, giving a pathetic cast to the face, whereas in the next figure, determination is expressed in part by brows that lower toward the nose, as well as by the outthrust chin and lower lip.

In anger, the brows are pulled still further down, and a frown wrinkle forms between them. Surprise is expressed by raised brows, a dropped chin, and widened eyes. Horror is an exaggeration of surprise. The brows are arched, as well as raised. The mouth is pulled open, causing tense lines to form from the nostrils downward. The eyes are widened still further, until they look as if they might drop out. The hair looks as if it were standing on end.

Smugness is expressed by a slight smile, raised brows, almost closed eyes, and a head tilted backward. Scorn is shown by lowered brows and lowered corners of the mouth which form harsh lines downward from the nostrils. Pathos is expressed by raised eyebrows which are higher toward the center of the forehead, closed eyes, and slightly parted lips with the corners pulled slightly downward. The head, relaxed and tilted to one side, and the rumpled hair add to the pathetic appearance.

Now look at each of these heads and imagine how the rest of the body would be drawn to match the facial expression, and you will see how important the position of the body is for the expressiveness of the cartoon. If a pathetic, drooping body is combined with a determined or a horrified facial expression, the result is incongruous.

COLOR

In nature, color is an effect of light. Without light, there is no color. Each color has a different wave length, and white

light is a product of all the lights of different colors or wave lengths. Light falling on surfaces of differing textures and consistencies is reflected and absorbed in different ways. Furthermore, many surfaces are selective. That is, a surface may absorb almost all of the colors except one. That color will penetrate only the top layer of the surface and then be reflected from it in such a way that the surface will appear to be composed of this one color. For example, a red tabletop reflects the red light which falls on it and absorbs most of the other light waves. In the same way pigments of the paint you use reflect certain colors and absorb the others.

Since the absorbtion of the light rays is never complete, the color of objects is never flat. Also some white light is usually reflected as a highlight on the object. As a consequence, in nature, a color is made up of a great number of hues, so that if an artist paints a red table with red pigment only, the painting will be dead in color in comparison with the real table. On the real table, many variations of light produce many subtle variations of hue, and the artist must paint the table with similar variations of hue, as well as of value, if he is to represent the real table adequately.

The commercial artist whose work is to be printed faces certain difficulties in this respect. In most printing processes, each separate color requires a separate plate and often a separate press run. This makes the use of even one color expensive. If more than one is to be used in order to approximate the number of hues in nature, the process becomes considerably more expensive than black and white reproduction.

Printed Color

When two colors of ink are used in printing a publication, usually one of the inks is black. Black ink contrasts with the paper and is generally easier to read. Occasionally, publications are printed in blue and a second color, or brown and a second color, in order to achieve certain effects.

In two-color printing, the second color of ink may be used for headings or initial letters or as backgrounds or frames

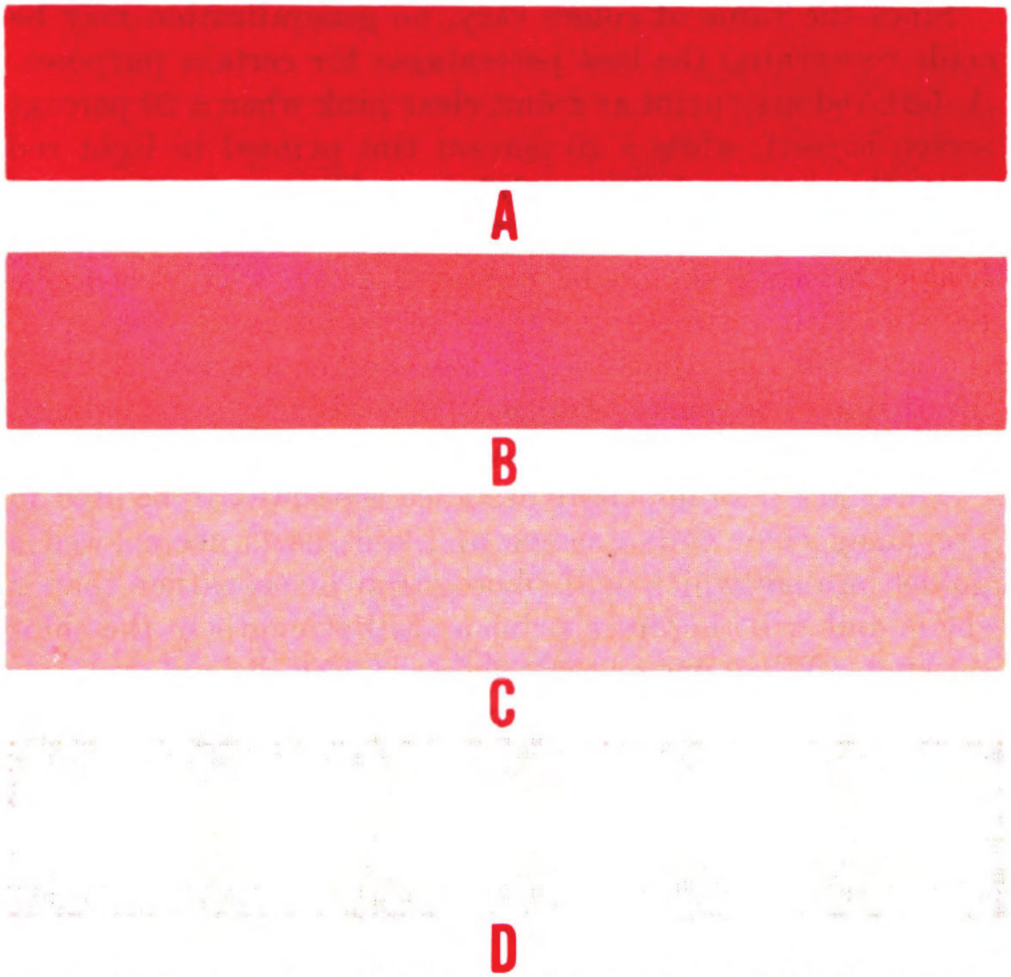


Figure 15–34.—A. Flat color printed full strength. B. With 80% screen. C. With 50%. D. With 20%.

for headings or artwork. Color printed in this manner is called FLAT COLOR. Flat color spots may be full strength or they may be reduced in strength. Color blocks may be provided by the artist, especially if the color spot is irregular in outline, or they may be made up by the printer.

A printer may regulate the strength of a color spot by using special patterns called Ben Day or by screening the area with a regular halftone screen which may be adjusted to form dots of various sizes. The ratio of color to white space, and therefore, the percentage of color concentration, depends on the size of the dots. In this case, the artist indicates the percentage of color concentration desired. (See fig. 15–34.)

Since the value of colors vary, no generalization may be made concerning the best percentages for certain purposes. A dark red may print as a fine, clear pink when a 20 percent screen is used, while a 20 percent tint printed in light red ink will appear too light and faded.

When the color spot is more than a simple square or rectangle, artwork should be prepared for it. If it is to be printed with artwork, it may be prepared as an overlay to the artwork. In that case, it may be rendered with black ink if it is to be printed full strength. If it is to be reduced in strength, shading sheets may be used.

There are shading sheets designed especially to be used in preparing color copy. Some of these sheets are colored a golden orange which will photograph black rather than a shade and will therefore print as full strength in the color selected. When one of these sheets is used, it is placed over the artwork and the color is scraped off the clear acetate with a stylus wherever no printed color is wanted. The resulting separation drawing will look like the separate tone outline in figure 15–35B, except that it will be in color. Figure 15–35C shows the tone printed as a color in register with the artwork.

The copy for the color plate, or for several color plates, may be prepared as a separate piece of artwork called a mechanical. For example, figure 15–36 shows the artwork for the cover of a publication which was printed in black, yellow, and blue. The unit shown in figure 15–36A is the basic mechanical. This was prepared the actual size of the cover, plus a bleed. The artwork for the yellow and blue plates could have been prepared as black mechanicals, or it could have been simply indicated by their outlines drawn in red on the original mechanical. Red will photograph and yet signify to the engraver that the lines are only guides.

The photographs were pasted up separately because they were of a larger size. (See fig. 15–37.) A photostat of the pasteup was placed on the mechanical to show the placement. (See fig. 15–36B.)

Figure 15–37 shows the finished cover in all three colors.

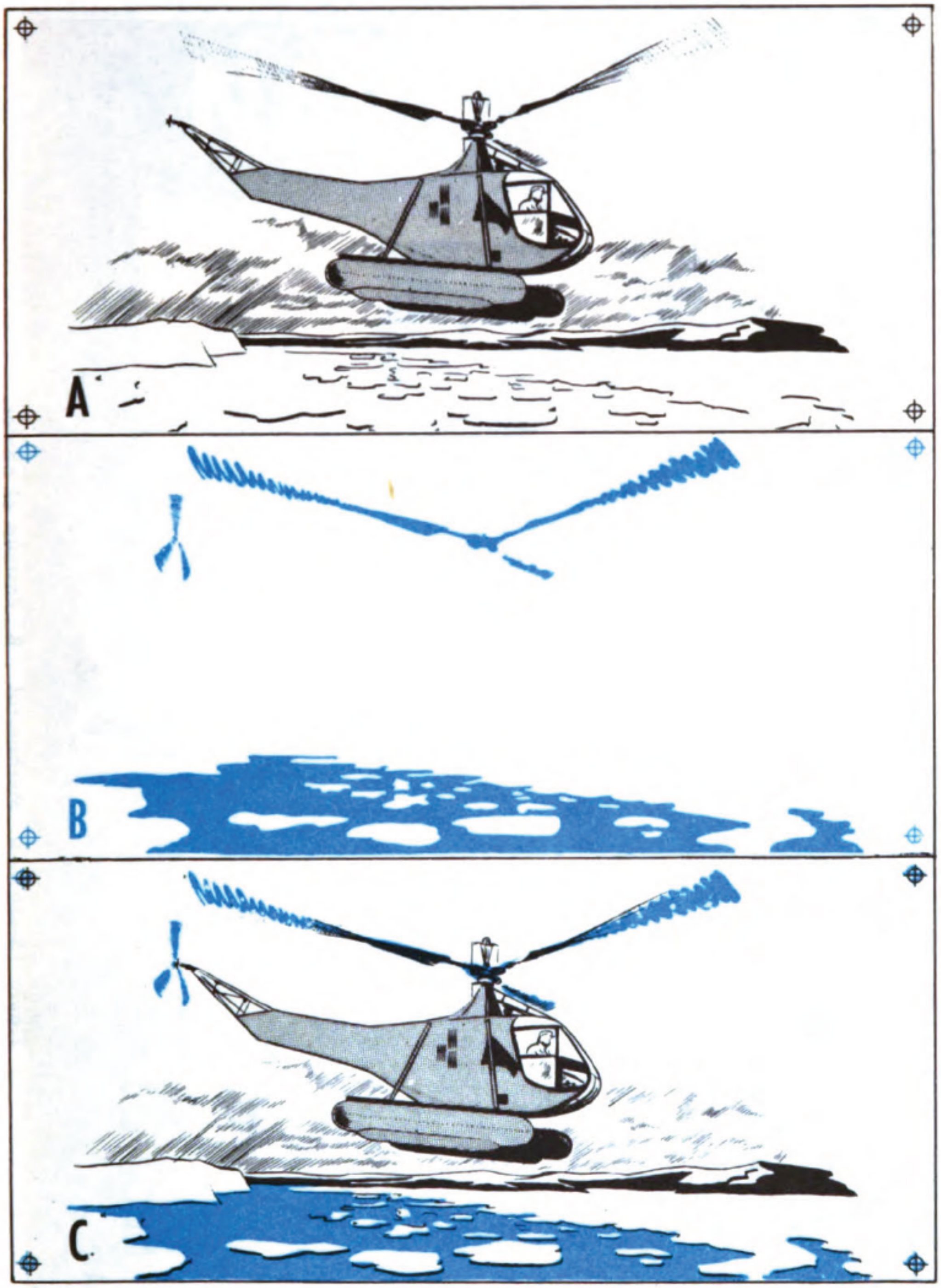


Figure 15–35.—A. Black and white artwork. B. Color separation drawing. C. Both plates printed in register.

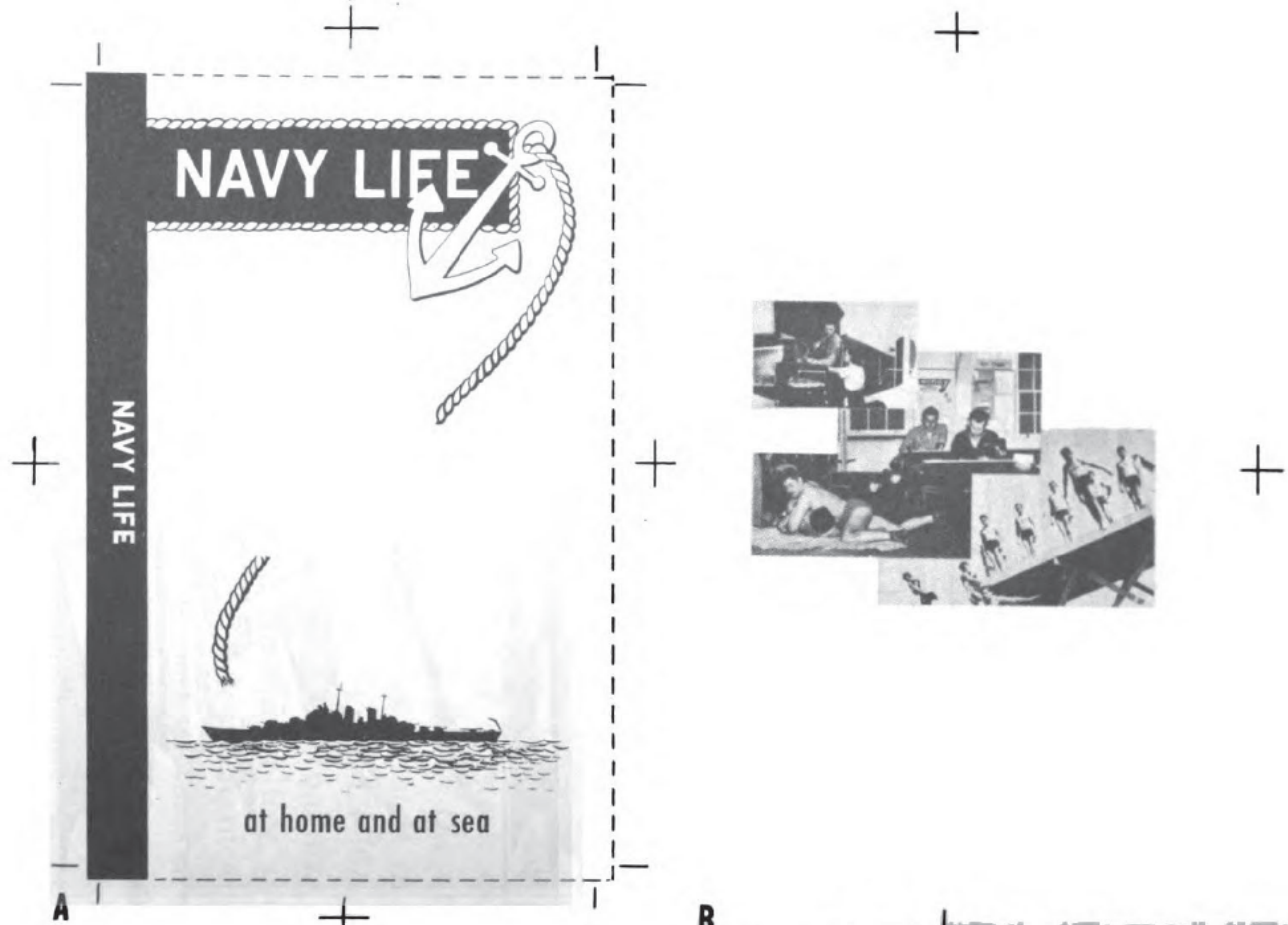


Figure 15–36.—A. Mechanical. B. Pasteup of photos.

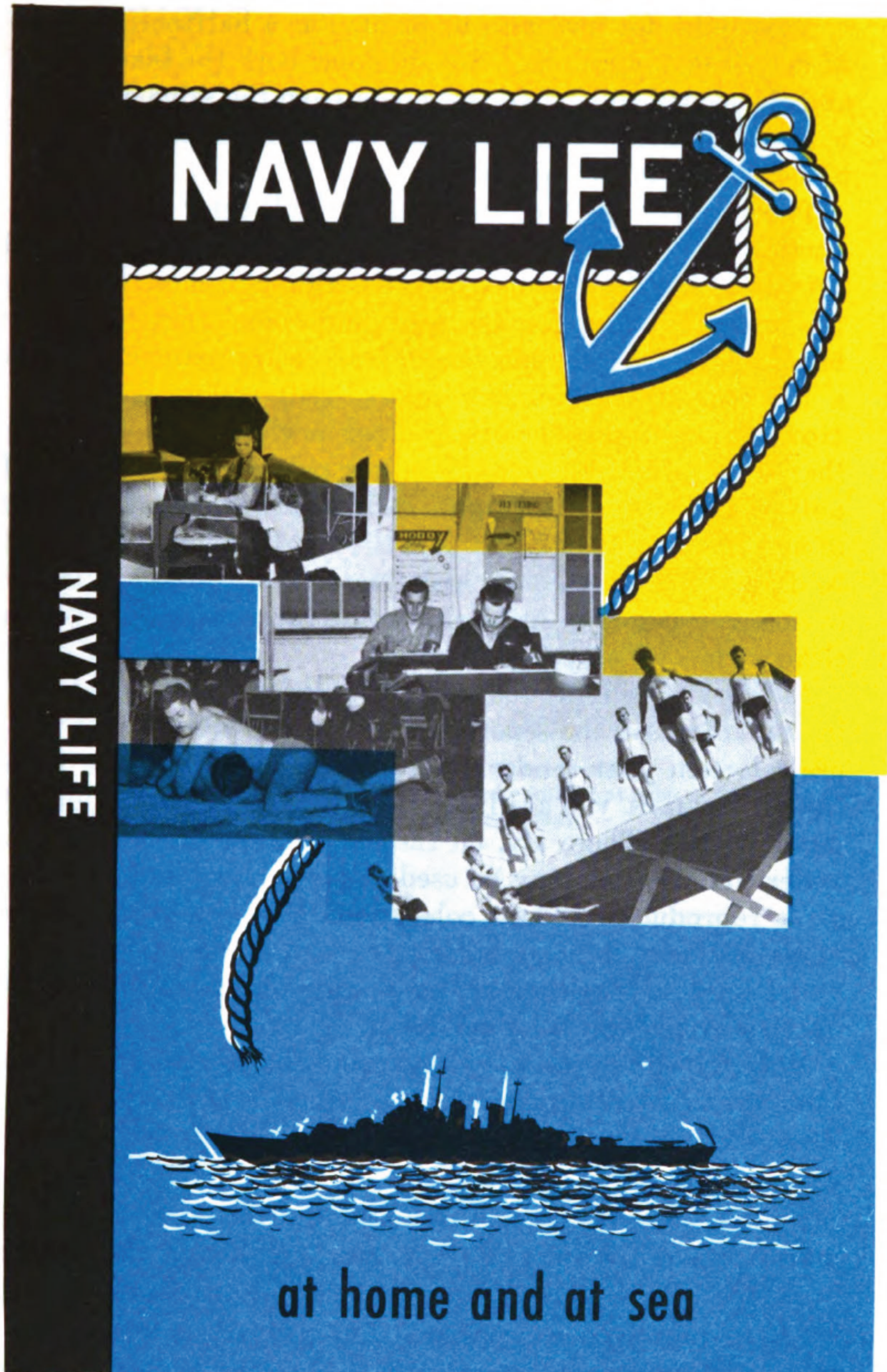


Figure 15–37.—Finished cover.

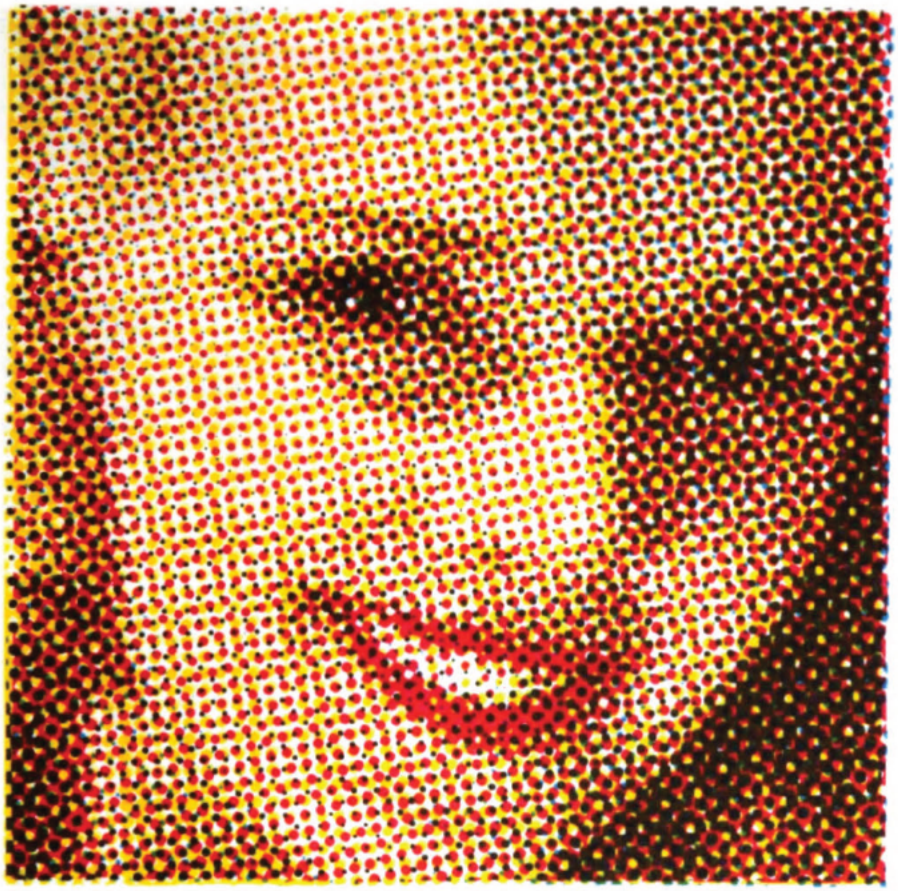
A second color may also be printed as a halftone, instead of flat, or as a DUOTONE. For duotone, both the black plate and the second color plate are made from the same copy but with a shift in the halftone screen so that the dots of the two plates are not superimposed.

PROCESS COLOR is the term used for full-color tone reproduction. In order to get perfect reproduction of original artwork, many colors may be used, although most commercial process printing consists of four-color work. This is based on the fact that most colors can be approximated from a mixture of the primary colors—red, yellow, and blue. However, in process colors, the red is closer to a magenta than a vermilion, the blue is rather pale and greenish, and only the yellow is the bright, clear shade we usually think of as a primary color. Black is the fourth color and is used to darken the other colors and create greater depth. However, a reproduction in process color rarely approaches the clean, rich color of a good original.

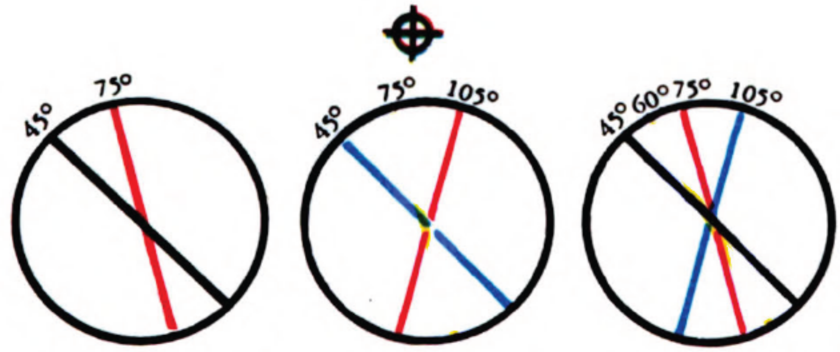
Artwork to be reproduced in full color is usually rendered in full color and the separation left to the printer. If you use colors in your rendering which are similar to the inks the printer uses, you are likely to get better reproduction of the artwork. There are, on the market, special fluorescent water colors which may be used to prepare colored artwork to be reproduced. These colors look like any other colors under ordinary lighting but fluoresce, or shine, under ultraviolet light so that they are especially adaptable for reproduction by photographic processes.

Figure 15–38 shows an enlargement of a section of process color work, revealing the screen structure. If this is viewed from the proper distance, the dots will disappear and the continuous tone of the original will be simulated.

Figure 15–39 shows how four-color printing is done. A plate is made for each of the colors. Although the means by which this is done in different printing processes varies, the basic principle is the same. The artwork is first photographed for each color separately. A different colored filter



Above, enlargement showing screen structure. If viewed from the proper distance, dots will disappear and continuous tone of the original will be perfectly simulated. Below, screen angles.



Angles for 2 colors

Angles for 3 colors

Angles for 4 colors

For the YELLOW	plate the VIOLET	Filter is used
For the RED	plate the GREEN	Filter is used
For the BLUE	plate the ORANGE	Filter is used
For the BLACK	plate the YELLOW	Filter is used

Courtesy Horan Engraving Co.

Figure 15–38.—Enlargement of four-color print.

A. Yellow printer negative made by photographing the colored copy through a blue filter.

B. Positive plate from the yellow negative, printed in black for study purpose.

C. Positive plate from the yellow negative (yellow printer) printed in yellow.

D. Red printer negative made by photographing the colored copy through a green filter.

E. Positive plate from the red negative (red printer) printed in red.

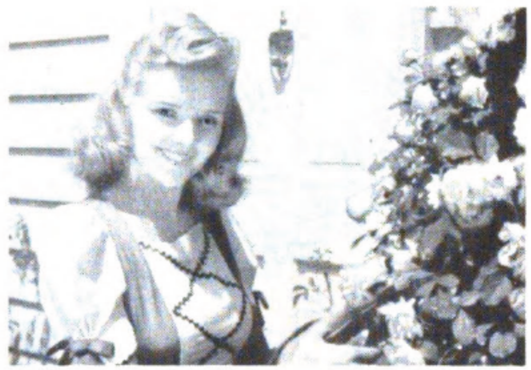
F. The yellow plate overprinted with the red plate.

G. Blue printer negative made by photographing the colored copy through a red filter.

H. Positive plate from the blue negative (blue printer) printed in blue.

I. Combined yellow, red, and blue printings.

J. Black printer negative made by photographing the colored copy through a yellow filter.



K. Positive plate from the black negative (black printer) printed in black.

L. Combined yellow, red, blue, and black printings.

Reproduced from a Kodacolor Print

Figure 15–39.—Separation negatives, plates, and progressive proofs as used in the four-color process.

is inserted in the camera for each color, except the black. Each of the filters screen out certain colors while making one photograph sharply. Since color separation is not more than 60 percent accurate, the negatives must be corrected for color before the plates are made. Correcting consists of staining or building up areas of the negative to make some areas of the cut light and reducing or etching areas of the negative to darken them. Finally, the negatives are transferred to plates and the finished plates are printed successively in register on the paper so that color is built up until a full-color print results.

Color Characteristics

A hue is a particular color, which is distinct from all other colors. A true red is a hue and so are orange red, violet, green, yellow, and yellow green. The hues of the spectrum blend together, but each gradation of the blend is a different hue. Only a few of these hues are shown on the color wheel in figure 15–40.

In order to identify colors, however, we need to know more than the hue. Each hue on the color wheel in figure 15–40 is represented in a single value. Actually each may be had in any value between white and black. For example, a hue of orange red may be lightened until it is almost white or it may be darkened until it is almost black, and it remains an orange red in hue. Under the color wheel in figure 15–40, both hue and value are represented with the hues approaching white in value at one end and black in value at the other.

The third property by which color is identified is its intensity or chroma. For example, the orange red may be grayed, usually by the addition of a little of its complementary color, that is, the color across from it on the color wheel. It will still be basically orange red in hue; it may have the same value exactly; but it looks different. This difference is one of intensity or concentration of the pigment of the hue. This grayed hue, in turn, may be rendered in all the values from white to black.

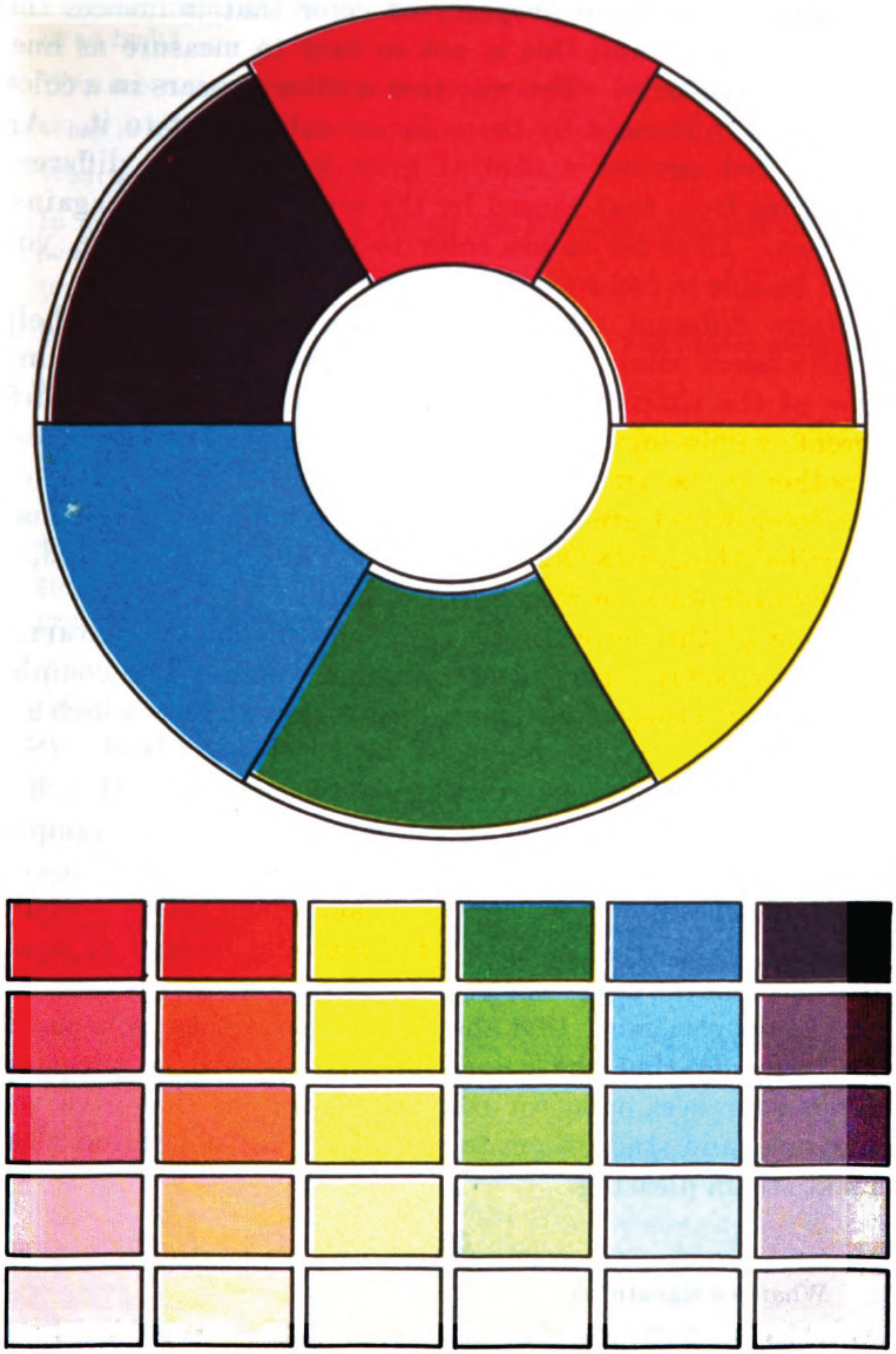


Figure 15–40.—Color wheel and value scale.

There is one more property of color that influences the way it appears and this is not so easy to measure as hue, value, or intensity. The way that a color appears in a color scheme is influenced by the color or colors next to it. An orange red against a neutral gray will cause a different sensation from that caused by the same orange red against a green. In order to use color to the best advantage, you must be able to feel such differences.

Many different schemes have been worked out to help artists select colors which will form pleasing combinations. One of the simplest is the MONOCHROMATIC, in which different values or intensities of the same hue are used. Another is the ANALOGOUS, in which hues closely related on the color wheel are used. One of the simplest of all may be called the DOMINANT. In this, one hue, such as a red, is used with a warm or a cool gray or both.

Some of the more complex schemes include the COMPLEMENTARY, SPLIT COMPLEMENT, and the TRIAD. The complementary consists, as its name indicates, of two hues which are complements, that is, opposites on the color wheel. (See fig. 15–40.) The split complement is composed of a hue and the hues on each side of its complement. For example, if violet is used, its complement is yellow, and the hues on each side of yellow—orange yellow and green yellow—would be used. The triad consists of three hues located at equal distances on the color wheel.

Always remember that the use of one of these schemes is no guaranty that the color combination will be pleasing. Keep your eyes open for color combinations that give you pleasure, and study them to see if you can determine what makes them pleasing.

QUIZ

1. What is a signature?
2. (a) How is the chisel-point pencil used to make gothic letters? (b) How is it used to make roman?
3. Why should you use large, black type sparingly on the printed page?

4. (a) How many points are there in a pica? (b) How many picas in an inch?
5. Why are roman type faces generally chosen for body type?
6. What is the effect of narrow margins on a page?
7. What is a double spread?
8. In an illustration, where should the strongest contrasts of tone be used?
9. What is color?
10. Why do some surfaces appear to be one color and others another?
11. Why is it that the color of real objects is never flat?
12. Why is it expensive to produce in printing a full-color duplicate of the original subject?
13. When the second color in two-color printing is used for color spots as type, backgrounds, or frames, what is it called?
14. How would you indicate to the printer that a color spot is to be printed in a reduced strength?
15. What is a mechanical?
16. What does the word REVERSE mean when it is used as an instruction to the printer?
17. What does the word FLOP mean on artwork?
18. What is meant by process color work?
19. How is artwork for full-color tone work usually rendered?
20. When you render full-color work to be printed by the four-color process, would you think it wise to use colors as close as possible to the inks that will be used?
21. What is meant by the hue of a color?
22. What is value?
23. What is intensity or chroma?

APPENDIX I

ANSWERS TO QUIZZES

CHAPTER 1

HOW YOU FIT IN

1. Twelve months.
2. The *Draftsman 2* training course.
3. On the military requirements for the E-5 pay grade and the professional qualifications for Draftsman 2 as prescribed in the *Manual of Qualifications for Advancement in Rating*, NavPers 10068.
4. Engineering handbooks contain material for reference which can't be remembered in detail and which is usually either tedious or impossible to compute.
5. In the *Catalog of Navy Material* or in the Navy Stock List which constitutes part of the *Federal Supply Catalog.*
6. In the *Index of Specifications and Standards, Used by Department of the Navy, Military Index*, Volume III.

CHAPTER 2

INSTRUMENTS AND EQUIPMENT

1. The case protects them from falls or from unnecessary pressures that may break or warp them, and the lining of the case helps prevent tarnishing or corroding.
2. Because there is no way to tighten a tongue joint after it has become worn.
3. The joints are bent and the points are brought together.
4. There will be difficulty in getting ink to flow.
5. A hard, fine-grained oilstone.
6. With the nibs screwed together, the pen is stroked lightly and evenly on the stone, starting at an angle of about 30° to the stone and swinging up to the vertical.

7. They are separated, then the outside surface of first one nib and then the other is moved across the stone with a rocking motion.
8. Stoning the inside surface may result in a slight convexity which is very undesirable.
9. The sliding pivot is moved until the desired ratio is obtained between the two sets of points.
10. To ensure cleanliness and to protect the board against nicks and scars.

CHAPTER 3

PICTORIAL DRAWINGS

1. The lines on perspective drawings are not drawn in proportion to the edges on the object.
2. Equal measure.
3. Isometric projections are made to a foreshortened isometric scale, whereas isometric drawings are made to a full scale.
4. 120°.
5. Isometric line. Non-isometric line.
6. When the long axis is parallel to the picture plane, the unpleasant effects of divergence are avoided.
7. By the co-ordinate method. Co-ordinate lines which are isometric lines are drawn to locate points on the non-isometric lines.
8. The co-ordinate method and the four-center method.
9. An isometric plane or a plane parallel to an isometric plane.
10. In the same isometric plane with, or in an isometric plane perpendicular to, the surfaces which are to be dimensioned.
11. Parallel to the viewing plane and undistorted as if it were an orthographic view.
12. At any angle except parallel or perpendicular to the horizontal.
13. A cabinet drawing.
14. Because the circle or irregular outline will appear distorted on the receding planes.
15. Because oblique drawings with long receding lines, drawn parallel to each other and not converging, appear distorted.
16. The major axis is at right angles to the shaft or rotation axis.
17. Objects appear smaller in proportion to their distance from the eye and receding lines converge to a vanishing point.
18. At an angle of 45°.
19. Shifting the center of the circle and springing the compass.

CHAPTER 4

MATHEMATICS

1. Three.
2. The fact that ratios between any two designated sides of a triangle are the same as those between the corresponding sides of all similar triangles.
3. The trigonometric functions.
4. Because the sine of the angle represents the ratio $\frac{\text{opposite side}}{\text{hypotenuse}}$, and in the second quadrant, the values of both of these sides are positive.
5. An angle of 76°.
6. The origin.
7. The quadrants.
8. (a) The abscissa. (b) The x axis.
9. The circle, ellipse, parabola, and hyperbola are called conics because they can be thought of as sections of a cone.
10. A parabola is a curve any point of which is equidistant from a fixed point, called the focus, and a fixed line, called the directrix.
11. A hyperbola is generated by a point moving so that the difference of its distance from two fixed points, called the focuses, is constant.
12. (a) A cycloid is generated by a point on the circumference of a circle that is rolled along a straight line. (b) An epicycloid is generated if the circle is rolled along the outside of another circle. (c) A hypercycloid is generated if the circle is rolled along the inside of another circle.
13. A helix is a curve in space which is generated by a point moving uniformly along a straight line which revolves around an axis.
14. The lead of a helix is the distance parallel with the axis which the point advances in one revolution.
15. They can be added in problems of multiplication and subtracted in problems of division, thus shortening the arithmetical processes involved.
16. A base of 10.
17. It indicates integral powers of 10 contained in the given number.
18. It is the number obtained by raising the base to the power indicated by a logarithm.
19. The A and B scales are used to find the squares and the square roots of numbers.

20. Place the hairline on the indicator over the number on the D scale and read the square under the indicator on the A scale.
21. Place the indicator over the number on the A scale and read the root under the indicator on the D scale.
22. The left scale or section.
23. The left section.

CHAPTER 5

MACHINE PARTS

1. Ferrous metals are those whose major proportion is iron; non-ferrous metals are those whose major proportions are not iron.
2. Pig iron.
3. Cast iron, wrought iron, and steel.
4. Its brittleness and low tensile strength.
5. Carbon and iron.
6. Low carbon steel can be easily cut, shaped, and welded. When the carbon content of the steel is over 0.75 percent, it can be readily hardened.
7. Its quality as a conductor of electricity.
8. (a) Brass. (b) For protection of ships' hulls and machinery against galvanic action caused by salt water.
9. Because pure aluminum is soft and not very strong.
10. Annealing, normalizing and hardening, which includes tempering and case hardening.
11. Thermosettings are heat hardened and will not burn readily, nor do they soften in hot water and absorb moisture; thermoplastics are not heat hardened and when heat is applied to them, they will either melt or become soft and pliable, some even absorbing a certain amount of moisture if they are placed in hot water.
12. These are metal products which require a high finish or close dimensional tolerances.
13. Casting is that process in which metal is melted and poured into molds where it is allowed to cool and harden.
14. The draft of a casting is the taper of the sides.
15. Forging is the process of working metal by hammering it into the desired shape after it has been heated to a plastic state.
16. It involves the forcing of hot metal through an opening in a die, causing the metal to take the shape of the die.
17. Turning, planing, milling, and drilling.

18. Grinding is used on a metal part to produce a smoother surface than can be produced by a cutting process.
19. In the *Catalog of Navy Material.*
20. The number of teeth to each inch of pitch diameter or number of teeth divided by the pitch diameter.
21. (a) The addendum is the height of the tooth above the pitch circle. (b) The dedendum is the length of the portion of the tooth from the pitch circle to the base of the tooth.
22. A spur gear is distinguished by the fact that the teeth are cut squarely across the outer rim of the gear blank in a direction parallel to the gear shaft axis.
23. No.
24. Bevel gears have teeth cut on an angular face for transmitting motion between shafts that are set at an angle to each other but are in the same plane.

CHAPTER 6

DEVELOPMENT OF SURFACES

1. Plane, plane-curved, warped, and double-curved.
2. Unfolding or unrolling the surface of a three-dimensional figure into a flat plane.
3. Parallel development, radial development, and triangulation.
4. For surfaces, such as prisms or cylinders, where the elements may be said to be parallel.
5. For surfaces, such as cones or pyramids, on which lines may be said to radiate from a single apex.
6. Surfaces which do not lend themselves to the other two methods.
7. With crosses near their ends.
8. The measurements of the edges to be joined should be checked to ensure that these edges will correspond exactly.
9. The intersection of the elements are located on orthographic views and then projected or transferred to the development.
10. (a) When a line appears as horizontal in the top view, the corresponding line in the front view is its true length. (b) When a line appears as horizontal in the front view, the corresponding line in the top view is its true length.
11. The line may be rotated to the horizontal by drawing an arc to the horizontal with the line as a radius.
12. The limits of these other edges may be projected onto the line of this edge in order to determine the true lengths.
13. The center of one end of the piece is not in line with that of the other end.
14. It is more practical for many types of figures, especially those involving warped surfaces.

15. The lines may be rotated to the horizontal in one view and the point thus found projected to the other view, or a true-length diagram may be drawn.

16. (a) The length of the base line of each right triangle equals the length of a line in the top view. (b) The altitude of the corresponding line in the front view. (c) The true length of the line.

CHAPTER 7

HEATING, VENTILATING, AND AIR CONDITIONING

1. For the comfort of personnel and for the preservation or best functioning of equipment.
2. The air contains half as much water as the maximum it can absorb.
3. Outside temperature, material of the walls, thickness of the walls, the amount of sunlight, and the heat given off within the enclosure.
4. Steam, hot water, and circulated warm air.
5. Oil-fired heaters and steam heat.
6. Because flammable vapors may be present.
7. With proper authorization, additional units could be added.
8. To preserve watertight integrity.
9. It should be waterproof.
10. In a supply line as near as practicable to the intake.
11. Centrifugal and axial flow.
12. On an exhaust line which might contain flammable vapors.
13. In a branch main.
14. The cfm of air to be delivered.
15. The whole system may be thrown off balance in so far as the proportion of air delivered to various compartments is concerned.
16. To prevent obstruction of air flow and to cut down noise.
17. Welded seam, lapped seam, grooved seam, and double seam.
18. They produce less turbulence in the airstream.
19. It proportions the amount of air directed into a branch.
20. When a duct has to pass through an armor deck.
21. To cut down the velocity of the discharged air.
22. An adjustable supply terminal.
23. When it is necessary to prevent condensation or objectionable gain or loss of heat.
24. In compartments where the presence of flammable vapors prohibits the use of electric machinery.

CHAPTER 8

AERONAUTICAL DRAFTING

1. 144 inches.
2. (a) To identify different parts when more than one part is shown on a single drawing. (b) To identify right-hand and left-hand parts.
3. The purpose of the drawing and the custom concerning that particular part or assembly.
4. Plumbing, wiring, and control linkage.
5. Because of the large size of many drawings.
6. The truss type and the monocoque type.
7. The semimonocoque.
8. Both are increased.
9. Their high strength-to-weight ratio, high resistance to corrosion, and comparative ease of fabrication.
10. The sharpest bend that can be put in a piece of metal without critically weakening it.
11. Round-head, brazier-head, flat head, countersunk head, and universal head.
12. The thickness of the materials to be riveted.
13. Cherry rivets, explosive rivets, rivnuts, and loc-rivets.
14. Use the same spacing as that used by the manufacturer in the surrounding area.
15. To join parts which are under very high tension, parts where repeated dismantling is necessary, or parts which are unsuitable for fastening by other means.
16. (a) Self-locking nuts. (b) Non-self-locking nuts.
17. Screws are, generally, made of lower strength material; they can be installed with a looser thread fit; and the shanks have no clearly defined grip.
18. Attaching cowling, fastening doors of baggage compartments, and fastening inspection openings.
19. Flexible lines are generally used in low pressure systems and for attachment of units that are subject to vibration.
20. To allow for expansion and contraction caused by temperature changes and to absorb vibration.
21. The tube will flatten and tend to wrinkle, kink, or crack.
22. A smooth curve with no slight reverse curves in it.
23. No. Templates are usually made from the drawing, and the sheet metal parts are made by using these templates.

CHAPTER 10

DRAWINGS, SPECIFICATIONS, AND TAKEOFFS FOR STRUCTURES

1. In the specifications which accompany the drawings of the structure.
2. It is convenient to speak of the scales as equations, but when the drawing is reduced from its original size, the equations are no longer valid for scaling purposes. However, scaling of the drawing can still be accomplished by using the graphic scales.
3. The standard Navy stock number.
4. G indicates that the particular article is listed in the General Stores Section of the *Catalog of Navy Material;* Y's and C's that an article is listed in the Yards and Docks Section.
5. They contain in writing information on materials, construction methods, tests, etc., which it is not practical to put in the drawings.
6. The takeoff.
7. A takeoff is a listing of the various materials needed for the job which is made directly from the detailed plans and specifications.
8. When an item is listed in terms of the wrong unit, too much or too little of the particular item may be delivered at the job.
9. Long tons of 2200 pounds.
10. Board foot.
11. Any measurement equivalent to a board which measures 1 foot long by 1 foot wide by 1 inch thick.
12. Dressed lumber is from ¼ inch to ½ inch less than the nominal size in width and thickness.
13. Usually, nails are estimated in pounds at so many pounds to 1,000 board feet measure or at so many pounds to a square of 100 square feet.
14. Cement, sand, gravel, or crushed stone, reinforcing steel, finishing materials, materials for forms, and materials for protection against freezing.
15. Concrete is measured as fixed or placed in the structure in cubic yards or cubic feet. Moldings, curbs, gutters, lintels, and such work are often measured by lineal foot with the other dimensions given so that the number of cubic yards or cubic feet may be found. Concrete finishing is measured by the square foot or square yard.
16. As three numbers, thus, 1: 2: 4, with the proportion of cement first, the proportion of sand second, and the proportion of gravel or crushed stone third.
17. The chemical action between the cement and the water.

18. By weight, assuming that a square bar 1 inch by 1 inch 12 inches long weighs 3.4 pounds. Steel fabric which is sold by the roll or sheet should be listed by size of mesh and weight per square foot, with the number of square feet given.
19. By the number of bricks per square foot of wall surface or the number of bricks per cubic foot of wall, with allowance for openings.
20. Cement, lime, sand, and water.
21. By the cubic yard or foot, or by the perch, which usually contains 24¾ cubic feet but may contain only 16½ cubic feet, depending on the locality.
22. A unit of 100 square feet, which is called a square.
23. (a) Piping, all types of fittings, packing and calking materials, and hangers with auxiliaries.
    (b) All plumbing fixtures.
24. Heat-generating units, heat-distributing units, heat-control system, heat-conveying system, and accessories.
25. (a) Rough work consists of conduit and wiring.
    (b) Finished work consists of electrical fixtures.

CHAPTER 11

SURVEYING, COMPUTING, AND PLOTTING

1. In terms of the curvature of the earth's surface.
2. Construction surveys, topographic surveys, and hydrographic surveys.
3. The foot.
4. In decimals.
5. The nearest 0.01 of a foot.
6. In referring to either the actual point indicated by a numbered stake or to the 100-foot unit distance.
7. In a first or second order survey with the polyconic projection.
8. An intercepted interval between the stadia hairs on the telescope of an engineer's transit is read on a stadia rod which is held at some distance from the observing instrument.
9. The value of the vertical angle which can be used with trigonometric functions to give the true distance.
10. A chart with lines joining all places where the magnetic declination is the same at any instant.
11. The purpose of leveling is to determine the difference in elevation between points or to determine the elevation at any given point.
12. It is the method of direct leveling used to determine differences in elevation.

13. It is used for determining elevations of low-order accuracy, and is particularly adaptable to uneven terrain where ordinary leveling sights would necessarily be short and to situations such as reconnaissance and pipeline surveys where the time element is a prime consideration.
14. It is defined as the field operations of measuring the lengths and angles of a series of straight lines connecting a series of points on the earth.
15. It is a drawing board, which can be leveled, mounted on a tripod, with an instrument called an alidade on top, which is used for taking sights.
16. It is set up over a station and oriented so that the point on the map on the drawing board which corresponds to the station is theoretically over the station and lines on the drawing board from this point will be parallel to lines on the ground.
17. For the centerline of roads and railroads which are to be constructed and for other construction projects or as a method for determining the intervisibility between two points on a map.
18. To determine the amount of earth to be moved to bring the ground to the proper grade.
19. The Lambert and Transverse Mercator projections.
20. They are distances north or south and east or west from a fixed point, called the origin, to any other point.
21. (a) Latitude. (b) Departure.
22. The protractor and scale method, the tangent method, chord method, or the rectangular coordinate method.
23. When the control system, usually a traverse, is not extensive or important.
24. Plotting by rectangular grid coordinates.
25. (a) Mean low water. (b) Mean lower low water. (c) Mean sea level.
26. (a) Near the time of the full moon and new moon, at which time the sun and moon act together to produce tides higher and lower than average. (b) When the moon is in the first or last quarter and it and the sun are opposed to each other.
27. It is the horizontal motion of water resulting from the vertical motion caused by tide.
28. (a) Set. (b) Drift.

CHAPTER 12

LETTERING

1. In points.
2. Twelve points in a pica and six picas to an inch.
3. The size of the block on which it is cast, rather than the letter on the face of the block.

4. Because we find it difficult to read.
5. By its mechanical regularity and hairline thins and serifs.
6. Since we are accustomed to reading book type which has serifs, the sans-serif letters are less legible than roman when they are set in blocks or full pages of type.
7. At this angle the letters are not seen as foreshortened and also the pen may be held horizontal, which makes it easier to control the ink flow.
8. When it is held tightly, you cannot feel what the nib is doing.
9. Because if they are too small, there will be a tendency for them to fill with ink when they are reproduced.
10. Because the optical center is slightly above the actual center of a letter.
11. The space between letters should be roughly equal. The letters themselves should be as close to the same width as the different letter forms allow, and the spaces, or counters, within the letters should be roughly the same.
12. Learning to see the letters, impressing them on your visual memory, and practicing them until the muscles of your hand have acquired a muscular memory of the letter forms.
13. To indicate differing features on the charts.
14. Type proofs are pulled on special media and the draftsman cuts out the letters and places them on the chart.
15. It means the opening up or stretching of words by inserting extra space between the letters.
16. Its character may alter completely, especially its weight or color.

CHAPTER 13

MAPS AND CHARTS

1. Mean sea level.
2. The meridian passing through Greenwich, England, near London.
3. The Equator is taken as the reference parallel.
4. Degrees, minutes, and seconds.
5. Clarke's spheroid of 1866.
6. The international nautical mile of 1,852 meters.
7. Mercator, gnomonic, Lambert conformal conic, and polyconic.
8. (1) Conformality. (2) Simplicity of construction. (3) Convenience in plotting positions from the border divisions. (4) The fact that a ship's course can be laid off from any meridian or compass rose within its borders. (5) Any straight line drawn on it in any direction is a rhumb line, or loxodromic curve.

9. The distances between parallels must be increased in proportion to the distance from the Equator; that is, by $\frac{1}{\cos}$, or the secant, of the latitude.

10. The great circle track line or shortest route on the earth's surface between the two points.

11. (1) For practical purposes there is only one scale for the entire map. (2) All directions within standard parallels are approximately true. (3) Great circles are very nearly straight lines. (4) When applied to large areas of E-W extension or to smaller sections within such an extension, it is remarkably accurate.

12. In the polyconic projection, the earth is considered to be a stack of innumerable thin horizontal cone slices.

13. (1) It is an extremely good projection for areas of wide latitude and narrow longitude. (2) E-W direction is fairly accurate. (3) There is universal scale, except near E-W boundaries. (4) Calculated general tables and mechanical ease of construction make for great popularity.

14. Plan borders and scale borders.

15. In general, plan borders are used for plans and plan charts with nautical scales of 1 : 49,999 or larger.

16. It means that the chart is reproduced at the sime size at which it is executed.

17. A sounding is a measurement of the depth of water which is expressed in feet or fathoms and reduced to the tidal datum shown in the chart title.

18. 1, 3, 6, 10, 20, 30, 50, 100, and 1,000.

19. They are drawn at even contour intervals like contour lines.

20. The skill and time it takes.

21. Because each point on a line represents points of equal elevation on the earth.

22. Generally, every fifth line on a contour line map is called an index line and is numbered according to its elevation and drawn heavier than the other lines.

23. Without experience or training in reading contour-line maps, a man will find it difficult to visualize the shape of the ground and also contour lines are always drawn as smooth, stylized curves, whereas the actual texture of the earth may be quite broken.

24. The universal transverse Mercator (UTM) grid is based on the transverse Mercator projection and the universal polar stereographic (UPS) grid is based on the polar stereographic projection.

CHAPTER 14

LITHOGRAPHIC DRAFTSMAN

1. Lithography.

2. Film stretches or shrinks with changes of temperature or humidity; glass is more stable and therefore provides a better register.

3. When a chart is too large to be photographed on a single negative, the left side is photographed on one negative and the right side on another. The negatives are then printed side by side on the plate but with a gap between them which must be filled in by a DML.
4. It is used for masking out large areas on the negative thus reducing the amount of opaquing to be done, and for masking out areas which are not to be printed on the plate.
5. Tusche is a lithographic drawing ink with a greasy base. It is used for drawing directly on the zinc plate.
6. To call them to the attention of the transferrer so that he will not fail to etch these areas.
7. Tint plates.
8. The base plate.
9. A plate on which a light blue image has been printed from the original or base negative.
10. Chalk powder offset plates are prepared if the original negative is damaged or lost.
11. Because magenta offers a good contrast to the other colors in the chart.
12. If large quantities of a chart are needed, a second or possibly a third zinc plate may have to be prepared in order to get a sharp image, and these plates can be made from a tint mask much faster than they can be prepared by hand.
13. A drop of glycerin or red ink.
14. A gage is a three-pronged brass fork used to make guide lines for lettering on the zinc plate.
15. The prongs of the gage would cut into the plate, and any scratches on the plate may print when the job is run on the press.
16. By opaquing.
17. Wax type is the trade name for type or cuts printed on sheets of waxed cellophane. It is used for paste-up purposes.
18. By painting over it with a coating of asphaltum before you begin engraving.

CHAPTER 15

LAYOUT AND ILLUSTRATION

1. A signature consists of several pages of a publication printed on the front and back of a single sheet of paper, which is folded to bring the pages into their proper order.
2. (a) It is turned so that each stroke is made with the wide side of the chisel. (b) The pencil is not turned and serifs and thin strokes are made with the thin side of the chisel.

3. Too much black makes the page difficult to read.
4. (a) Twelve points. (b) Six picas.
5. The serifs of roman type help bind letters together as words, so that it is easier to read the type.
6. They make the page look black and crowded and therefore more difficult to read.
7. The facing pages of a publication.
8. On the most dramatic elements.
9. An effect of light; different colors are caused by light waves of different lengths.
10. Surfaces differ in absorbing light rays. Some absorb almost all of the light wave lengths except one, and this they reflect in such a way that they appear to be composed of this color.
11. The absorption of light rays is never complete.
12. In most printing processes, each separate color requires a separate plate and often a separate press run.
13. Flat color.
14. By marking percentage of color concentration desired in the area.
15. Artwork prepared to be used by the printer in making a color plate or several color plates.
16. REVERSE means that the part so indicated should be printed in the opposite color. For example, white lettering on a black ground is lettering in reverse.
17. Reverse in position.
18. Full-color tone reproduction.
19. It is usually rendered in full color and the separation left to the printer.
20. Yes. The process red is closer to a magenta than a vermilion, the blue rather pale and greenish, and only the yellow a bright, clear, primary shade.
21. A hue is a particular color which is distinct from all other colors.
22. Value is the gradation between white and black of a hue.
23. The amount of concentration of pigments of the particular hue, undiluted by gray or by pigment of a complementary hue.

APPENDIX II

QUALIFICATIONS FOR ADVANCEMENT IN RATING

DRAFTSMAN (DM)

RATING CODE NO. 3200

General Service Rating

SCOPE

Draftsmen prepare, file, and check topographical, hydrographical, architectural, structural, mechanical, and electrical drawings, plans, sketches, tracings, illustrations, maps, and charts from rough or detailed sketches, notes, and illustrations, using pencil, ink, colors, or lithographic greases; prepare, modify, file, and check statistical charts and diagrams from information provided; prepare specifications, material estimates, and bills of material; make, correct, and file blueprints; operate blueprint machines or similar printing machines to reproduce drawings; letter and sketch; make computations required of draftsmen; cut, lay out, arrange, and mount photographs, lettering, and sketches to form required patterns, designs, and maps.

Emergency Service Ratings

DRAFTSMEN S (Structural), Rating Code No. 3201 .... **DMS**
Work on drawings for construction of airfields, water-front installations, pipe lines, buildings, drainage systems, and other advanced-base facilities.

DRAFTSMEN E (Electrical), Rating Code No. 3202 .... **DME**
Work on drawings of electrical, telephone-wiring, and power-supply systems.

DRAFTSMEN I (Illustrators), Rating Code No. 3203 .... **DMI**
Work on drawings, posters, illustrations, and layouts used for publicity and as training aids.

DRAFTSMEN L (Lithographic), Rating Code No. 3204 .... **DML**
Perform drafting work on lithographic plates.

DRAFTSMEN T (Topographic), Rating Code No. 3205 .... **DMT**

Work on hydrographic and topographic maps and charts.

DRAFTSMEN M (Mechanical), Rating Code No. 3206 .... **DMM**

Work on drawings of mechanical devices, machine parts, aeronautical structures, ship structures, and heating, ventilating, and plumbing systems.

Navy Job Classifications and Codes

For specific Navy job classifications included within this rating and the applicable job codes, see Manual of Enlisted Navy Job Classifications, NavPers 15105 (Revised), codes DM–3700 to DM–3799.

Qualifications for Advancement in Rating

Qualifications for advancement in rating	Applicable rates						
	DM	DMS	DME	DMI	DML	DMT	DMM
100 PRACTICAL FACTORS							
101 OPERATIONAL							
1. Select and use drafting instruments; choose and use pens for freehand and mechanical drawing	3	3	3	3	3	3	3
2. Read and interpret simple drawings and sketches	3	3	3	3	3	3	3
3. Make blueprints, vandykes, blackline prints, or Ozalid prints	3	3	3	3	3	3	3
4. Letter neatly and legibly with lettering devices or freehand in pencil and ink	3	3	3	3	3	3	3
5. Measure and subdivide distances on drawings and maps	3	3	3	3	3	3	3
6. Copy, trace, and delineate cartographic and engineering data	3	3	3	3	3	3	3
7. Make simple drawings in ink and pencil	3	3	3	3	3	3	3
8. Transfer cartographic and engineering data from one scale to another	3	3	3	3	3	3	3

Qualifications for advancement in rating	Applicable rates						
	DM	DMS	DME	DMI	DML	DMT	DMM
9. Select views, layout, and make drawings in two-view or three-view orthographic projections	3	3	3	3	----	----	3
10. Identify materials commonly used in construction work	3	3	3	----	----	----	3
11. Plot geographic positions and draw magnetic and true course, distance, and variation curves	3	3	----	----	3	3	----
12. Operate:							
a. Planimeter	3	----	----	----	----	3	----
b. Electric ratio projector	3	----	----	----	----	3	----
c. Pantograph	3	----	----	----	----	3	----
d. Slide rule	3	3	3	----	----	3	3
13. Outline and shade land and water areas with lithographic greases if so assigned	3	----	----	----	3	----	----
14. Translate ideas and drawings clearly and accurately into working sketches	2	2	2	2	2	2	2
15. Select views, lay out, and make isometric drawings	2	2	2	2	----	----	2
16. Perform the following computations:							
a. Reduce survey notes to a form suitable for drafting	2	2	----	----	----	2	----
b. Interpolation	2	2	----	----	2	2	----
c. Determine local magnetic change and annual change from the World Variation Charts	2	2	----	----	2	2	----
17. Letter neatly and legibly in ink or pencil in various types, including Gothic, roman, italic, Old English, and modern	2	----	----	2	2	----	----
18. Prepare under supervision specifications for the following types of work:							

Qualifications for advancement in rating	Applicable rates						
	DM	DMS	DME	DMI	DML	DMT	DMM
a. Electrical	2	----	2	----	----	----	----
b. Structural	2	2	----	----	----	----	----
c. Mechanical	2	----	----	----	----	----	2
19. Make the following types of drawings:							
a. Illustrative layouts including both decorative and special posters and placards	2	----	----	3	----	----	----
b. Mechanical layouts of small heating and ventilating installation and of small drainage and pumping systems including pipe sizes, valves, and fittings	2	----	----	----	----	----	2
c. Layouts of electrical distribution systems and wiring diagrams including wire sizes and boxes	2	--	----	2	----	----	----
d. Topographic layouts including profiles, traverses, contours, and cross sections from notes	2	2	----	----	----	2	----
e. Architectural layouts and structural drawings and details for light wood frame, heavy timber, and steel structures including foundation and footings	2	2	----	----	----	----	----
20. Make minor changes on lithographic plates, matching lettering styles, symbols, and features, accurately preserving and rearranging cartographic data, and using the proper erasing, graining, and drawing materials and techniques; mix solutions used in lithographic drafting if so assigned	2	----	----	----	3	----	----

Qualifications for advancement in rating	Applicable rates						
	DM	DMS	DME	DMI	DML	DMT	DMM
21. Select views, layout, and make perspective drawings	1	1	1	1	----	----	1
22. Perform detailed drafting	1	1	1	----	----	1	1
23. Construct a Mercator's projection	1	----	----	----	1	1	----
24. Make drafting changes on lithographic plates, matching lettering styles, symbols, and features, accurately preserving and rearranging cartographic data, and using proper materials and procedures for etching and counter-etching if so assigned	1	----	----	----	2	----	----
102 MAINTENANCE AND/OR REPAIR							
1. Maintain instruments used by draftsmen	3	3	3	3	3	3	3
2. Care for:							
a. Planimeter	3	----	----	----	----	3	----
b. Electric ratio projector	3	----	----	----	----	3	----
c. Pantograph	3	----	----	----	----	3	----
d. Slide rule	3	3	3	----	----	3	3
103 ADMINISTRATIVE AND/OR CLERICAL							
1. File drawings, blueprints, tracings, and drafting data	3	3	3	3	3	3	3
2. Make takeoffs, bills of materials, and quantity estimates from finished drawings	2	2	2	----	----	----	2
3. Check and edit tracings and originals for accuracy, workmanship, neatness, and conformity to accepted drafting standards	1	1	1	1	1	1	1
4. Supervise and train personnel engaged in drafting operations	1	1	1	1	1	1	1

Qualifications for advancement in rating	Applicable rates						
	DM	DMS	DME	DMI	DML	DMT	DMM
5. Prepare neat and accurate operational and progress reports and organizational charts	1	1	1	1	1	1	1
6. Prepare requisitions for drafting materials or equipment	1	1	1	1	1	1	1
7. Prepare neat and accurate detailed specifications	1	1	1	----	----	----	1
8. Organize and administer a drafting room or section	C	C	C	C	C	C	C
200 EXAMINATION SUBJECTS							
201 OPERATIONAL							
1. Principles of good composition and layout	3	3	3	3	3	3	3
2. Drafting or drawing in accordance with joint Army-Navy standards	3	3	3	3	3	3	3
3. Selection of scales, principal views, dimensions, and line weights	3	3	3	3	3	3	3
4. Methods of making blueprints, vandykes, blackline prints, and Ozalid prints	3	3	3	3	3	3	3
5. Decimals and fractions; computation of areas and volumes	3	3	3	3	3	3	3
6. Standard symbols and nomenclature commonly used on the following:							
a. Charts and maps	3	3	----	----	3	3	------
b. Mechanical drawings	3	3	3	----	----	----	3
c. Structural drawings	3	3	----	----	----	----	------
d. Electrical drawings	3	3	3	----	----	----	3
7. Conversion of degrees, minutes, and seconds into nautical and statute miles	3	3	----	----	3	3	------

Qualifications for advancement in rating	Applicable rates						
	DM	DMS	DME	DMI	DML	DMT	DMM
8. Extraction of roots and raising of numbers to powers by the use of logarithms; solution of simple problems in plane geometry and trigonometry	2	2	2	----	----	2	2
9. Use of mechanical, electrical, civil, and architectural engineering handbooks	2	2	2	----	----	2	2
10. Elementary surveying procedures; surveying terms and instruments	2	2	----	----	2	2	----
11. Use of tide and current tables	2	2	----	----	2	2	----
12. Characteristics and uses of Mercator's projection or grid	2	----	----	----	2	2	----
13. Scaling of geographic features; distinction between graphic and numerical or natural scales	2	----	----	----	2	2	----
14. Use of colors in illustrations and drawings	2	----	----	3	----	----	----
15. Coordinates of the earth and distances on a sphere; relative position of the poles, equator, and Greenwich meridian; magnetic variations, magnetic and true north, and latitude and longitude	2	----	----	----	2	2	----
16. Characteristics and uses of motors, generators, and common electrical devices and systems	1	1	2	----	----	----	2
17. Characteristics and uses of pumps, heating equipment, ventilation units and systems, water treatment units, and similar mechanical devices	1	1	----	----	----	----	1

Qualifications for advancement in rating	DM	DMS	DME	DMI	DML	DMT	DMM
18. Construction and uses of ship members and structures	1	----	1	----	----	----	1
19. Theory and characteristics of polyconic, azimuthal, and conformal projections	1	----	----	----	1	1	----
20. Principles of drainage; airfield layout and advanced base design and layout	1	1	----	----	----	----	----
21. Fundamentals of design of structures commonly found at air stations such as hangars, runways, control towers, GCA stands, seaplane ramps, and CIC radar control rooms	1	1	----	----	----	----	----
22. Principles of statics, including definition of work, power, and energy; mechanical advantages in the uses of levers, pulleys, wheels, axles, and inclined planes	C	C	----	----	----	----	----
23. Procedure and method of transferring information from polyconic and Mercator's projections to polar projections	C	----	----	----	1	1	----
24. Principles of running traverses, topographic surveys, hydrographic surveys, and laying out of control grids	C	----	----	----	----	----	----
202 MAINTENANCE AND/OR REPAIR							
1. Maintenance of commonly used drafting instruments and tools	3	3	3	3	3	3	
203 ADMINISTRATIVE AND/OR CLERICAL							
1. Methods and procedures for filing blueprints, drawings, tracings, and drafting data	3	3	3	3	3	3	3

APPENDIX III.—NATURAL SINES AND COSINES

M.	0°		1°		2°		3°		4°		
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	
0	0.00000	1.0000	0.01745	0.99985	0.03490	0.99939	0.05234	0.99863	0.06976	0.99756	60
1	029	000	774	984	519	938	263	861	.07005	754	59
2	058	000	803	984	548	937	292	860	034	752	58
3	087	000	832	983	577	936	321	858	063	750	57
4	116	000	862	983	606	935	350	857	092	748	56
5	.00145	1.0000	.01891	.99982	.03635	.099934	.05379	.99855	.07121	.99746	55
6	175	000	920	982	664	933	408	854	150	744	51
7	204	000	949	981	693	932	437	852	179	742	53
8	233	000	978	980	723	931	466	851	208	740	52
9	262	000	.02007	980	752	930	495	849	237	738	51
10	.00291	1.0000	.02036	.99979	.03781	.99929	.05524	.99847	.07266	.99736	50
11	320	.99999	065	979	810	927	553	846	295	734	49
12	349	999	094	978	839	926	582	844	324	731	48
13	378	999	123	977	868	925	611	842	353	729	47
14	407	999	152	977	897	924	640	841	382	727	46
15	.00436	.99999	.02181	.99976	.03926	.99923	.05669	.99839	.07411	.99725	45
16	465	999	211	976	955	922	698	838	440	723	44
17	495	909	240	975	984	921	727	836	469	721	43
18	524	999	269	974	.04013	919	756	834	498	719	42
19	553	998	298	974	042	918	785	833	527	716	41
20	.00582	.99998	.02327	.99973	.04071	.99917	.05814	.99831	.07556	.99714	40
21	611	998	356	972	100	916	844	829	585	712	39
22	640	998	385	972	129	915	873	827	614	710	38
23	669	998	414	971	159	913	902	826	643	708	37
24	698	998	443	970	188	912	931	824	672	705	36
25	.00727	.99997	.02472	.99969	.04217	.99911	.05960	.99822	.07701	.99703	35
26	756	997	501	969	246	910	989	821	730	701	34
27	785	907	530	968	275	909	.06018	819	759	699	33
28	814	997	560	967	304	907	047	817	788	696	32
29	844	996	589	966	333	906	076	815	817	694	31
30	.00873	.99996	.02618	.99966	.04362	.99905	.06105	.99813	.07846	.99692	30
31	902	996	647	965	391	904	134	812	875	689	29
32	931	.996	676	964	420	902	163	810	904	687	28
33	960	995	705	963	449	901	192	808	933	685	27
34	969	995	734	963	478	900	221	806	962	683	26
35	.01018	.99995	.02763	.99962	.04507	.99898	.06250	.99804	.07991	.99680	25
36	017	995	792	961	536	897	279	803	.08020	678	24
37	076	994	821	960	565	896	308	801	049	676	23
38	105	994	850	959	594	894	337	799	078	673	22
39	134	994	879	959	623	893	366	797	107	671	21
40	.01164	.99993	.02908	.99958	.04653	.99892	.06395	.99795	.08136	.99668	20
41	193	993	938	957	682	890	424	793	165	666	19
42	222	993	967	956	711	889	453	792	194	664	18
43	251	992	996	955	740	888	482	790	223	661	17
44	280	992	.03025	954	769	886	511	788	252	659	16
45	.01309	.99991	.03054	.99953	.04798	.99885	.06540	.99786	.08281	.99657	15
46	338	991	083	952	827	883	569	784	310	654	14
47	367	991	112	952	856	882	598	782	339	652	13
48	396	990	141	951	885	881	627	780	368	649	12
49	425	900	170	950	914	879	656	778	397	647	11
50	.01454	.99989	.03199	.99949	.04943	.99878	.06685	.99776	.08426	.99644	10
51	483	989	228	948	972	876	714	774	455	642	9
52	513	989	257	947	.05001	875	743	772	484	639	8
53	512	988	286	946	030	873	773	770	513	637	7
54	571	988	316	945	059	872	802	768	542	635	6
55	.01600	.99987	.03345	.99944	.05088	.99870	.06831	.99766	.08571	.99632	5
56	629	987	374	943	117	869	860	764	600	630	4
57	658	986	403	942	146	867	889	762	629	627	3
58	687	986	432	941	175	866	918	760	658	625	2
59	716	985	461	940	205	864	947	758	687	622	1
60	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	.08716	.99619	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	89°		88°		87°		86°		85°		

M.	5°		6°		7°		8°		9°		
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	
0	0.08716	0.99619	0.10453	0.99452	0.12187	0.99255	0.13917	0.99027	0.15643	0.98769	60
1	745	617	482	449	216	251	946	023	672	764	59
2	774	614	511	446	245	248	975	019	701	760	58
3	803	612	540	443	274	244	.14004	015	730	755	57
4	831	609	569	440	302	240	033	011	758	751	56
5	.08860	.99607	.10597	.99437	.12331	.99237	.14061	.99006	.15787	.98746	55
6	889	604	626	434	360	233	090	002	816	741	54
7	918	602	655	431	389	230	119	.98998	845	737	53
8	947	599	684	428	418	226	148	994	873	732	52
9	976	596	713	424	447	222	177	990	902	728	51
10	.09005	.99594	.10742	.99421	.12476	.99219	.14205	.98986	.15931	.98723	50
11	034	591	771	418	504	215	234	982	959	718	49
12	063	588	800	415	533	211	263	978	988	714	48
13	092	586	829	412	562	208	292	973	.16017	709	47
14	121	583	858	409	591	204	320	969	046	704	46
15	.09150	.99580	.10887	.99406	.12620	.99200	.14349	.98965	.16074	.98700	45
16	179	578	916	402	649	197	378	961	103	695	44
17	208	575	945	399	678	193	407	957	132	690	43
18	237	572	973	396	706	189	436	953	160	686	42
19	266	570	.11002	393	735	186	464	948	189	681	41
20	.09295	.99567	.11031	.99390	.12764	.99182	.14493	.98944	.16218	98676	40
21	324	564	060	386	793	178	522	940	246	671	39
22	353	562	089	383	822	175	551	936	275	667	38
23	382	559	118	380	851	171	580	931	304	662	37
24	411	556	147	377	880	167	608	927	333	657	36
25	.09440	.99553	.11176	.99374	.12908	.99163	.14637	.98923	.16361	.98652	35
26	469	551	205	370	937	160	666	919	390	648	34
27	498	548	234	367	966	156	695	914	419	643	33
28	527	545	263	364	995	152	723	910	447	638	32
29	556	542	291	360	.13024	148	752	906	476	633	31
30	.09585	.99540	.11320	.99357	.13053	.99144	.14781	.98902	.16505	.98629	30
31	614	537	349	354	081	141	810	897	533	624	29
32	642	534	378	351	110	137	838	893	562	619	28
33	671	531	407	347	139	133	867	889	591	614	27
34	700	528	436	344	168	129	896	884	620	609	26
35	.09729	.99526	.11465	.99341	.13197	.99125	.14925	.98880	.16648	.98604	25
36	758	523	494	337	226	122	954	876	677	600	24
37	787	520	523	334	254	118	982	871	706	595	23
38	816	517	552	331	283	114	.15011	867	734	590	22
39	845	514	580	327	312	110	040	863	763	585	21
40	.09874	.99511	.11609	.99324	.13341	.99106	.15069	.98858	.16792	.98580	20
41	903	508	638	320	370	102	097	854	820	575	19
42	932	506	667	317	399	098	126	849	849	570	18
43	961	503	696	314	427	094	155	845	878	565	17
44	990	500	725	310	456	091	184	841	906	561	16
45	.10019	.99497	.11754	.99307	.13485	.99087	.15212	.98836	.16935	.98556	15
46	048	494	783	303	514	083	241	832	964	551	14
47	077	491	812	300	543	079	270	827	992	546	13
48	106	488	840	297	572	075	299	823	.17021	541	12
49	135	485	869	293	600	071	327	818	050	536	11
50	.10164	.99482	.11898	.99290	.13629	.99067	.15356	.98814	.17078	.98531	10
51	192	479	927	286	658	063	385	809	107	526	9
52	221	476	956	283	687	059	414	805	136	521	8
53	250	473	985	279	716	055	442	800	164	516	7
54	279	470	.12014	276	744	051	471	796	193	511	6
55	.10308	.99467	.12043	.99272	.13773	.99047	.15500	.98791	.17222	.98506	5
56	337	464	071	269	802	043	529	787	250	501	4
57	366	461	100	265	831	039	557	782	279	496	3
58	395	458	129	262	860	035	586	778	308	491	2
59	424	455	158	258	889	031	615	773	336	486	1
60	.10453	.99452	.12187	99255	.13917	.99027	.15643	.98769	.17365	.98481	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	84°		83°		82°		81°		80°		

APPENDIX III.—Natural sines and cosines—Continued

M	10° Sin.	10° Cos.	11° Sin.	11° Cos.	12° Sin.	12° Cos.	13° Sin.	13° Cos.	14° Sin.	14° Cos.	
0	0.17365	0.98481	0.19081	0.98163	0.20791	0.97815	0.22495	0.97437	0.24192	0.97030	60
1	393	476	109	157	820	809	523	430	220	023	59
2	422	471	138	152	848	803	552	424	249	015	58
3	451	466	167	146	877	797	580	417	277	008	57
4	479	461	195	140	905	791	608	411	305	001	56
5	.17508	.98455	.19224	.98135	.20933	.97784	.22637	.97404	.24333	.96994	55
6	537	450	252	129	962	778	665	398	362	987	54
7	565	445	281	124	990	772	693	391	390	980	53
8	594	440	309	118	.21019	766	722	384	418	973	52
9	623	435	338	112	047	760	750	378	446	966	51
10	.17651	.98430	.19366	.98107	.21076	.97754	.22778	.97371	.24474	.96959	50
11	680	425	395	101	104	748	807	365	503	952	49
12	708	420	423	096	132	742	835	358	531	945	48
13	737	414	452	090	161	735	863	351	559	937	47
14	766	409	481	084	189	729	892	345	587	930	46
15	.17794	.98404	.19509	.98079	.21218	.97723	.22920	.97338	.24615	.96923	45
16	823	399	538	073	246	717	948	331	644	916	44
17	852	394	566	067	275	711	977	325	672	909	43
18	880	389	595	061	303	706	.23005	318	700	902	42
19	909	383	623	056	331	698	033	311	728	894	41
20	.17937	.98378	.19652	.98050	.21360	.97692	.23062	.97304	.24756	.96887	40
21	966	373	680	044	388	686	090	298	784	880	39
22	995	368	709	039	417	680	118	291	813	873	38
23	.18023	362	737	033	445	673	146	284	841	866	37
24	052	357	766	027	474	667	175	278	869	858	36
25	.18081	.98352	.19794	.98021	.21502	.97661	.23203	.97271	.24897	.96851	35
26	109	347	823	016	530	655	231	264	925	844	34
27	138	341	851	010	559	648	260	257	954	837	33
28	166	336	880	004	587	642	288	251	982	829	32
29	195	331	908	.97998	616	636	316	244	.25010	822	31
30	.18224	.98325	.19937	.97992	.21644	.97630	.23345	.97237	.25038	.96815	30
31	252	320	965	987	672	623	373	230	066	807	29
32	281	315	994	981	701	617	401	223	094	800	28
33	309	310	.20022	975	729	611	429	217	122	793	27
34	338	304	051	969	758	604	458	210	151	786	26
35	.18367	.98299	.20079	.97963	.21786	.97598	.23486	.97203	.25179	.96778	25
36	395	294	108	958	814	592	514	196	207	771	24
37	424	288	136	952	843	585	542	189	235	764	23
38	452	283	165	946	871	579	571	182	263	756	22
39	481	277	193	940	899	573	599	176	291	749	21
40	.18509	.98272	.20222	.97934	.21928	.97566	.23627	.97169	.25320	.96742	20
41	538	267	250	928	956	560	656	162	348	734	19
42	567	261	279	922	985	553	684	155	376	727	18
43	595	250	307	916	.22013	547	712	148	404	719	17
44	624	250	336	910	041	541	740	141	432	712	16
45	.18652	.98245	.20364	.97905	.22070	.97534	.23769	.97134	.25460	.96705	15
46	681	240	393	899	098	528	797	127	488	697	14
47	710	234	421	893	126	521	825	120	516	690	13
48	738	229	450	887	155	515	853	113	545	682	12
49	767	223	478	881	183	508	882	106	573	675	11
50	.18795	.98218	.20507	.97875	.22212	.97502	.23910	.97100	.25601	.96667	10
51	824	212	535	869	240	496	938	093	629	660	9
52	852	207	563	863	268	489	966	086	657	653	8
53	881	201	592	857	297	483	995	079	685	645	7
54	910	196	620	851	325	476	.24023	072	713	638	6
55	.18938	.98190	.20649	.97845	.22353	.97470	.24051	.97065	.25741	.96630	5
56	967	185	677	839	382	463	079	.058	769	623	4
57	995	179	706	833	410	457	108	051	798	615	3
58	.19024	174	734	827	438	450	136	044	826	608	2
59	052	168	763	821	467	444	164	037	854	600	1
60	.19081	.98163	.20791	.97815	.22495	.97437	.24192	.97030	.25882	.96593	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	79°		78°		77°		76°		75°		

APPENDIX III.—Natural sines and cosines—Continued

M.	15°		16°		17°		18°		19°		
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	
0	0.25882	0.96593	0.27564	0.96126	0.29237	0.95630	0.30902	0.95106	0.32557	0.94552	60
1	910	585	502	118	265	622	929	097	584	542	59
2	938	578	620	110	293	613	957	088	612	533	58
3	966	570	648	102	321	605	985	079	639	523	57
4	994	562	676	094	348	596	.31012	070	667	514	56
5	.26022	.96555	.27704	.96086	.29376	.95588	.31040	.95061	.32694	.94504	55
6	050	547	731	078	404	579	068	052	722	495	54
7	079	540	759	070	432	571	095	043	749	485	53
8	107	532	787	062	460	562	123	033	777	476	52
9	135	524	815	054	487	554	151	024	804	466	51
10	.26163	.96517	.27843	.96046	.29515	.95545	.31178	.95015	.32832	.94457	50
11	191	509	871	037	543	536	206	006	859	447	49
12	219	502	899	029	571	528	233	.94997	887	438	48
13	247	494	927	021	599	519	261	988	914	428	47
14	275	486	955	013	626	511	289	979	942	418	46
15	.26309	.96479	.27983	.96005	.29654	.95502	.31316	.94970	.32969	.94409	45
16	331	471	.28011	.95997	682	493	344	961	997	399	44
17	359	463	039	989	710	485	372	952	.33021	390	43
18	387	456	067	981	737	476	399	943	051	380	42
19	415	448	095	972	765	467	427	933	079	370	41
20	.26443	.96440	.28123	.95964	.29793	.95459	.31454	.94924	.33106	.94361	40
21	471	433	150	956	821	430	482	915	134	351	39
22	500	425	178	948	849	411	510	906	161	342	38
23	528	417	206	940	876	433	537	807	189	332	37
24	556	410	234	931	904	424	565	888	216	322	36
25	.26584	.96402	.28262	.95923	.29932	.95415	.31593	.94878	.33244	.94313	35
26	612	394	290	915	960	407	620	869	271	303	34
27	640	386	318	907	987	398	648	860	298	293	33
28	668	379	346	898	.30015	389	675	851	326	284	32
29	696	371	374	890	043	380	703	842	353	274	31
30	.26724	.96363	.28402	.95882	.30071	.95372	.31730	.94832	.33381	.94264	30
31	752	355	429	874	098	363	758	823	408	254	29
32	780	347	457	865	126	354	786	814	436	245	28
33	808	340	485	857	154	345	813	805	463	235	27
34	836	332	513	849	182	337	841	795	490	225	26
35	.26864	.96324	.28541	.95841	.30209	.95328	.31868	.94786	.33518	.94215	25
36	892	316	569	832	237	319	896	777	545	206	24
37	920	308	597	824	265	310	923	768	573	196	23
38	948	301	625	816	292	301	951	758	600	186	22
39	976	293	652	807	320	293	979	749	627	176	21
40	.27004	.96285	.28680	.95799	.30348	.95284	.32006	.94740	.33655	.94167	20
41	032	277	708	791	376	275	034	730	682	157	19
42	060	269	736	782	403	266	061	721	710	147	18
43	088	261	764	774	431	257	089	712	737	137	17
44	116	253	792	766	459	248	116	702	764	127	16
45	.27144	.96246	.28820	.95757	.30486	.95240	.32144	.94693	.33792	.94118	15
46	172	238	847	749	514	231	171	684	819	108	14
47	200	230	875	740	542	222	199	674	846	098	13
48	228	222	903	732	570	213	227	665	874	088	12
49	256	214	931	724	597	204	254	656	901	078	11
50	.27284	.96206	.28959	.95715	.30625	.95195	.32282	.94646	.33929	.94068	10
51	312	198	987	707	653	186	309	637	956	058	9
52	340	190	.29015	698	680	177	337	627	983	049	8
53	368	182	042	690	708	168	364	618	.34011	039	7
54	396	174	070	681	736	159	392	609	038	029	6
55	.27424	.96166	.29098	.95673	.30763	.95150	.32419	.94599	.34065	.94019	5
56	452	158	126	664	791	142	447	590	093	009	4
57	480	150	154	656	819	133	474	580	120	.93999	3
58	508	142	182	647	846	124	502	571	147	989	2
59	536	134	209	639	874	115	529	561	175	979	1
60	.27564	.96126	.29237	.95630	.30902	.95106	.32557	.94552	.34202	.93969	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	74°		73°		72°		71°		70°		

APPENDIX III.—Natural sines and cosines—Continued

M.	20°		21°		22°		23°		24°		
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	
0	0.34202	0.93969	0.35837	0.93358	0.37461	0.92718	0.39073	0.92050	0.40674	0.91355	60
1	229	959	864	348	488	707	100	039	700	343	59
2	257	949	891	337	515	697	127	028	727	331	58
3	284	939	918	327	542	686	153	016	753	319	57
4	311	929	945	316	569	675	180	005	780	307	56
5	.34339	.93919	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295	55
6	366	909	.36000	295	622	653	234	982	833	283	54
7	393	899	027	285	649	642	260	971	860	272	53
8	421	889	054	274	676	631	287	959	886	260	52
9	448	879	081	264	703	620	314	948	913	248	51
10	.34475	.93869	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236	50
11	503	859	135	243	757	598	367	925	966	224	49
12	530	849	162	232	784	587	394	914	992	212	48
13	557	839	190	222	811	576	421	902	.41019	200	47
14	584	829	217	211	838	565	448	891	045	188	46
15	.34612	.93819	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176	45
16	639	809	271	190	892	543	501	868	098	164	44
17	666	799	298	180	919	532	528	856	125	152	43
18	694	789	325	169	946	521	555	845	151	140	42
19	721	779	352	159	973	510	581	833	178	128	41
20	.34748	.93769	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116	40
21	775	759	406	137	.38026	488	635	810	231	104	39
22	803	748	434	127	053	477	661	799	257	092	38
23	830	738	461	116	080	466	688	787	284	080	37
24	857	728	488	106	107	455	715	775	310	068	36
25	.34884	.93718	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056	35
26	912	708	542	084	161	432	768	752	363	044	34
27	939	698	569	074	188	421	795	741	390	032	33
28	966	688	596	063	215	410	822	729	416	020	32
29	993	677	623	052	241	399	848	718	443	008	31
30	.35021	.93667	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996	30
31	048	657	677	031	295	377	902	694	496	984	29
32	075	647	704	020	322	366	928	683	522	972	28
33	102	637	731	010	349	355	955	671	549	960	27
34	130	626	758	.92999	376	343	982	660	575	948	26
35	.35157	.93616	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936	25
36	184	606	812	978	430	321	035	636	628	924	24
37	211	596	839	967	456	310	062	625	655	911	23
38	239	585	867	956	483	299	088	613	681	899	22
39	266	575	894	945	510	287	115	601	707	887	21
40	.35293	.93565	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875	20
41	320	555	948	924	564	265	168	578	760	863	19
42	347	544	975	913	591	254	195	566	787	851	18
43	375	534	.37002	902	617	243	221	555	813	839	17
44	402	524	029	892	644	231	248	543	840	826	16
45	.35429	.93514	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814	15
46	456	503	083	870	698	200	301	519	892	802	14
47	484	493	110	859	725	198	328	508	919	790	13
48	511	483	137	840	752	186	355	496	945	778	12
49	538	472	164	838	778	175	381	484	972	766	11
50	.35565	.93462	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753	10
51	592	452	218	816	832	152	434	461	.42024	741	9
52	619	441	245	805	859	141	461	449	051	729	8
53	647	431	272	794	886	130	488	437	077	717	7
54	674	420	299	784	912	119	514	425	104	704	6
55	.35701	.93410	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692	5
56	728	400	353	762	966	096	567	402	156	680	4
57	755	389	380	751	993	085	594	390	183	668	3
58	782	379	407	740	.39020	073	621	378	209	655	2
59	810	368	434	729	046	062	647	366	235	643	1
60	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	.42262	.90631	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	69°		68°		67°		66°		65°		

APPENDIX III.—Natural sines and cosines—Continued

M.	25°		26°		27°		28°		29°		
	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	
0	0.42262	0.90631	0.43837	0.89879	0.45399	0.89101	0.46947	0.88295	0.48481	0.87462	60
1	288	618	863	867	425	087	973	281	506	448	59
2	315	606	889	854	451	074	999	267	532	434	58
3	341	594	916	841	477	061	.47024	254	557	420	57
4	367	582	942	828	503	048	050	240	583	406	56
5	.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	.48608	.87391	55
6	420	557	994	803	554	021	101	213	634	377	54
7	446	545	.44020	790	580	008	127	199	659	363	53
8	473	532	046	777	606	.88995	153	185	684	349	52
9	499	520	072	764	632	981	178	172	710	335	51
10	.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	.48735	.87321	50
11	552	495	124	739	684	955	229	144	761	306	49
12	578	483	151	726	710	942	255	130	786	292	48
13	604	470	177	713	736	928	281	117	811	278	47
14	631	458	203	700	762	915	306	103	837	264	46
15	.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	.48862	.87250	45
16	683	433	255	674	813	888	358	075	888	235	44
17	709	421	281	662	839	875	383	062	913	221	43
18	736	408	307	649	865	862	409	048	938	207	42
19	762	396	333	636	891	848	434	034	964	193	41
20	.42788	.90383	.44359	.89623	.45917	.88835	.47460	.88020	.48989	.87178	40
21	815	371	385	610	942	822	486	006	.49014	164	39
22	811	358	411	597	968	808	511	.87993	040	150	38
23	867	346	437	584	994	795	537	979	065	136	37
24	894	334	464	571	.46020	782	562	905	090	121	36
25	.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	.49116	.87107	35
26	946	309	516	545	072	755	614	937	141	093	34
27	972	296	542	532	097	741	639	923	166	079	33
28	999	284	568	519	123	728	665	909	192	064	32
29	.43025	271	594	506	149	715	690	896	217	050	31
30	.43051	.90259	.44620	.89493	.46175	.88701	.47716	.87882	.49242	.87036	30
31	077	246	646	480	201	688	741	868	268	021	29
32	104	233	672	467	226	674	767	854	293	007	28
33	130	221	698	454	252	661	793	840	318	.86993	27
34	156	208	724	441	278	647	818	826	344	978	26
35	.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	.49369	.86964	25
36	209	183	776	415	330	620	869	798	394	949	24
37	235	171	802	402	355	607	895	784	419	935	23
38	261	158	828	389	381	593	920	770	445	921	22
39	287	146	854	376	407	580	946	756	470	906	21
40	.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87743	.49495	.86892	20
41	340	120	906	350	458	553	997	729	521	878	19
42	366	108	932	337	484	539	.48022	715	546	863	18
43	392	095	958	324	510	526	048	701	571	849	17
44	418	082	984	311	536	512	073	687	596	834	16
45	.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	.49622	.86820	15
46	471	057	036	285	587	485	124	659	647	805	14
47	497	045	062	272	613	472	150	645	672	791	13
48	523	032	088	259	639	458	175	631	697	777	12
49	549	019	114	245	664	445	201	617	723	762	11
50	.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	.49748	.86748	10
51	602	.89994	166	219	716	417	252	589	773	733	9
52	628	981	192	206	742	404	277	575	798	719	8
53	654	968	218	193	767	390	303	561	824	704	7
54	680	956	243	180	793	377	328	546	849	690	6
55	.43706	.89943	.45269	.89167	.46819	.88363	.48354	.87532	.49874	.86675	5
56	733	930	295	153	844	349	379	518	899	661	4
57	759	918	321	140	870	336	405	504	924	646	3
58	785	905	347	127	896	322	430	490	950	632	2
59	811	892	373	114	921	308	456	476	975	617	1
60	.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	.50000	.86603	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	64°		63°		62°		61°		60°		

APPENDIX III.—Natural sines and cosines—Continued

M.	30° Sin.	30° Cos.	31° Sin.	31° Cos.	32° Sin.	32° Cos.	33° Sin.	33° Cos.	34° Sin.	34° Cos.	
0	0.50000	0.86603	0.51504	0.85717	0.52992	0.84805	0.54464	0.83867	0.55919	0.82904	60
1	025	588	529	702	.53017	789	488	851	943	887	59
2	050	573	554	687	041	774	513	835	968	871	58
3	076	559	579	672	066	759	537	819	992	855	57
4	101	544	604	657	091	743	561	804	.56016	839	56
5	.50126	.86530	.51628	.85642	.53115	.84728	.54586	.83788	.56040	.82822	55
6	151	515	653	627	140	712	610	772	064	806	54
7	176	501	678	612	164	697	635	756	088	790	53
8	201	486	703	597	189	681	659	740	112	773	52
9	227	471	728	582	214	666	683	724	136	757	51
10	.50252	.86457	.51753	.85567	.53238	.84650	.54708	.83708	.56160	.82741	50
11	277	442	778	551	263	635	732	692	184	724	49
12	302	427	803	536	288	619	756	676	208	708	48
13	327	413	828	521	312	604	781	660	232	692	47
14	352	398	852	506	337	588	805	645	256	675	46
15	.50377	.86384	.51877	.85491	.53361	.84573	.54829	.83629	.56280	.82659	45
16	403	369	902	476	386	557	854	613	305	643	44
17	428	354	927	461	411	542	878	597	329	626	43
18	453	340	952	446	435	526	902	581	353	610	42
19	478	325	977	431	460	511	927	565	377	593	41
20	.50503	.86310	.52002	.85416	.53484	.84495	.54951	.83549	.56401	.82577	40
21	528	295	026	401	509	480	975	533	425	561	39
22	553	281	051	385	534	464	999	517	449	544	38
23	578	266	076	370	558	448	.55024	501	473	528	37
24	603	251	101	355	583	433	048	485	497	511	36
25	.50628	.86237	.52126	.85340	.53607	.84417	.55072	.83469	.56521	.82495	35
26	654	222	151	325	632	402	097	453	545	478	34
27	679	207	175	310	656	386	121	437	569	462	33
28	704	192	200	294	681	370	145	421	593	446	32
29	729	178	225	279	705	355	169	405	617	429	31
30	.50754	.86163	.52250	.85264	.53730	.84339	.55194	.83389	.56641	.82413	30
31	779	148	275	249	754	324	218	373	665	396	29
32	804	133	299	234	779	308	242	356	689	380	28
33	829	119	324	218	804	292	266	340	713	363	27
34	854	104	349	203	828	277	291	324	736	347	26
35	.50879	.86089	.52374	.85188	.53853	.84261	.55315	.83308	.56760	.82330	25
36	904	074	399	173	877	245	339	292	784	314	24
37	929	059	423	157	902	230	363	276	808	297	23
38	954	045	448	142	926	214	388	260	832	281	22
39	979	030	473	127	951	198	412	244	856	264	21
40	.51004	.86015	.52498	.85112	.53975	.84182	.55436	.83228	.56880	.82248	20
41	029	000	522	096	.54000	167	460	212	904	231	19
42	054	.85985	547	081	024	151	484	195	928	214	18
43	079	970	572	066	049	135	509	179	952	198	17
44	104	956	597	051	073	120	533	163	976	181	16
45	.51129	.85941	.52621	.85035	.54097	.84104	.55557	.83147	.57000	.82165	15
46	154	926	646	020	122	088	581	131	024	148	14
47	179	911	671	005	146	072	605	115	047	132	13
48	204	896	696	.84989	171	057	630	098	071	115	12
49	229	881	720	974	195	041	654	082	095	098	11
50	.51254	.85866	.52745	.84959	.54220	.84025	.55678	.83066	.57119	.82082	10
51	279	851	770	943	244	009	702	050	143	065	9
52	304	836	794	928	269	.83994	726	034	167	048	8
53	329	821	819	913	293	978	750	017	191	032	7
54	354	806	844	897	317	962	775	001	215	015	6
55	.51379	.85792	.52869	.84882	.54342	.83946	.55799	.82985	.57238	.81999	5
56	404	777	893	866	366	930	823	969	262	982	4
57	429	762	918	851	391	915	847	953	286	965	3
58	454	747	943	836	415	899	871	936	310	949	2
59	479	732	967	820	440	883	895	920	334	932	1
60	.51504	.85717	.52992	.84805	.54464	.83867	.55919	.82904	.57358	.81915	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	59°		58°		57°		56°		55°		

APPENDIX III.—Natural sines and cosines—Continued

M.	35° Sin.	35° Cos.	36° Sin.	36° Cos.	37° Sin.	37° Cos.	38° Sin.	38° Cos.	39° Sin.	39° Cos.	
0	0.57358	0.81915	0.58779	0.80902	0.60182	0.79864	0.61566	0.78801	0.62932	0.77715	60
1	381	899	802	885	205	846	589	783	955	696	59
2	405	882	826	867	228	829	612	765	977	678	58
3	429	865	849	850	251	811	635	747	.63000	660	57
4	453	848	873	833	274	793	658	729	022	641	56
5	.57477	.81832	.58896	.80816	.60298	.79776	.61681	.78711	.63045	.77623	55
6	501	815	920	799	321	758	704	694	068	605	54
7	524	798	943	782	344	741	726	676	090	586	53
8	548	782	967	765	367	723	749	658	113	568	52
9	572	765	990	748	390	706	772	640	135	550	51
10	.57596	.81748	.59014	.80730	.60414	.79688	.61795	.78622	.63158	.77531	50
11	619	731	037	713	437	671	818	604	180	513	49
12	643	714	061	696	460	653	841	586	203	494	48
13	667	698	084	679	483	635	864	568	225	476	47
14	691	681	108	662	506	618	887	550	248	458	46
15	.57715	.81664	.59131	.80644	.60529	.79600	.61909	.78532	.63271	.77439	45
16	738	647	154	627	553	583	932	514	293	421	44
17	762	631	178	610	576	565	955	496	316	402	43
18	786	614	201	593	599	547	978	478	338	384	42
19	810	597	225	576	622	530	.62001	460	361	366	41
20	.57833	.81580	.59248	.80558	.60645	.79512	.62024	.78442	.63383	.77347	40
21	857	563	272	541	668	494	046	424	406	329	39
22	881	546	295	524	691	477	069	405	428	310	38
23	904	530	318	507	714	459	092	387	451	292	37
24	928	513	342	489	738	441	115	369	473	273	36
25	.57952	.81496	.59365	.80472	.60761	.79424	.62138	.78351	.63496	.77255	35
26	976	479	389	455	784	406	160	333	518	236	34
27	999	462	412	438	807	388	183	315	540	218	33
28	.58023	445	436	420	830	371	206	297	563	199	32
29	047	428	459	403	853	353	229	279	585	181	31
30	.58070	.81412	.59482	.80386	.60876	.79335	.62251	.78261	.63608	.77162	30
31	094	395	506	368	899	318	274	243	630	144	29
32	118	378	529	351	922	300	297	225	653	125	28
33	141	361	552	334	945	282	320	206	675	107	27
34	165	344	576	316	968	264	342	188	698	088	26
35	.58189	.81327	.59599	.80299	.60991	.79247	.62365	.78170	.63720	.77070	25
36	212	310	622	282	.61015	229	388	152	742	051	24
37	236	293	646	264	038	211	411	134	765	033	23
38	260	276	669	247	061	193	433	116	787	014	22
39	283	259	693	230	084	176	456	098	810	.76996	21
40	.58307	.81242	.59716	.80212	.61107	.79158	.62479	.78079	.63832	.76977	20
41	330	225	739	195	130	140	502	061	854	959	19
42	354	208	763	178	153	122	524	043	877	940	18
43	378	191	786	160	176	105	547	025	899	921	17
44	401	174	809	143	199	087	570	007	922	903	16
45	.58425	.81157	.59832	.80125	.61222	.79069	.62592	.77988	.63944	.76884	15
46	449	140	856	108	245	051	615	970	966	866	14
47	472	123	879	091	268	033	638	952	989	847	13
48	496	106	902	073	291	016	660	934	.64011	828	12
49	519	089	926	056	314	.78998	683	916	033	810	11
50	.58543	.81072	.59949	.80038	.61337	.78980	.62706	.77897	.64056	.76791	10
51	567	055	972	021	360	962	728	879	078	772	9
52	590	038	995	003	383	944	751	861	100	754	8
53	614	021	.60019	.79986	406	926	774	843	123	735	7
54	637	004	042	968	429	908	796	824	145	717	6
55	.58661	.80987	.60065	.79951	.61451	.78891	.62819	.77806	.64167	.76698	5
56	684	970	089	934	474	873	842	788	190	679	4
57	708	953	112	916	497	855	864	769	212	661	3
58	731	936	135	899	520	837	887	751	234	642	2
59	755	919	158	881	543	819	909	733	256	623	1
60	.58779	.80902	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	0
	Cos. 54°	Sin. 54°	Cos. 53°	Sin. 53°	Cos. 52°	Sin. 52°	Cos. 51°	Sin. 51°	Cos. 50°	Sin. 50°	M.

APPENDIX III.—Natural sines and cosines—Continued

M.	40° Sin.	40° Cos.	41° Sin.	41° Cos.	42° Sin.	42° Cos.	43° Sin.	43° Cos.	44° Sin.	44° Cos.	
0	0.64279	0.76604	0.65606	0.75471	0.66913	0.74314	0.68200	0.73135	0.69466	0.71934	60
1	301	586	628	452	935	295	221	116	487	914	59
2	323	567	650	433	956	276	242	096	508	894	58
3	346	548	672	414	978	256	264	076	529	873	57
4	368	530	694	395	999	237	285	056	549	853	56
5	.64390	.76511	.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
6	412	492	738	356	043	198	327	016	591	813	54
7	435	473	759	337	064	178	349	.72996	612	792	53
8	457	455	781	318	086	159	370	976	633	772	52
9	479	436	803	299	107	139	391	957	654	752	51
10	.64501	.76417	.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
11	524	398	847	261	151	100	434	917	696	711	49
12	546	380	869	241	172	080	455	897	717	691	48
13	568	361	891	222	194	061	476	877	737	671	47
14	590	342	913	203	215	041	497	857	758	650	46
15	.64612	.76323	.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
16	635	304	956	165	258	002	539	817	.800	610	44
17	657	286	978	146	280	.73983	561	797	821	590	43
18	679	267	.66000	126	301	963	582	777	842	569	42
19	701	248	022	107	323	944	603	757	862	549	41
20	.64723	.76229	.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
21	746	210	066	069	366	904	645	717	904	508	39
22	768	192	088	050	387	885	666	697	925	488	38
23	790	173	109	030	409	865	688	677	946	468	37
24	812	154	131	011	430	846	709	657	966	447	36
25	.64834	.76135	.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
26	856	116	175	973	473	806	751	617	.70008	407	34
27	878	097	197	953	495	787	772	597	029	386	33
28	901	078	218	934	516	767	793	577	049	366	32
29	923	059	240	915	538	747	814	557	070	345	31
30	.64945	.76041	.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
31	967	022	284	876	580	708	857	517	112	305	29
32	989	003	306	857	602	688	878	497	132	284	28
33	.65011	.75984	327	838	623	669	899	477	153	264	27
34	033	965	349	818	645	649	920	457	174	243	26
35	.65055	.75946	.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
36	077	927	393	780	688	610	962	417	215	203	24
37	100	908	414	760	709	590	983	397	236	182	23
38	122	889	436	741	730	570	.69004	377	257	162	22
39	144	870	458	722	752	551	025	357	277	141	21
40	.65166	.75851	.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
41	158	832	501	683	795	511	067	317	319	100	19
42	210	813	523	664	816	491	088	297	339	080	18
43	232	794	545	644	837	472	109	277	360	059	17
44	254	775	566	625	859	452	130	257	381	039	16
45	.65276	.75756	.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
46	298	738	610	586	901	413	172	216	422	.70998	14
47	320	719	632	567	923	393	193	196	443	978	13
48	342	700	653	548	944	373	214	176	463	957	12
49	364	680	675	528	965	353	235	156	484	937	11
50	.65386	.75661	.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
51	408	642	718	489	.68008	314	277	116	525	896	9
52	430	623	740	470	029	294	298	095	546	875	8
53	452	604	762	451	051	274	319	075	567	855	7
54	474	585	783	431	072	254	340	055	587	834	6
55	.65496	.75566	.66805	.74412	68093	.73234	.69361	.72035	.70608	.70813	5
56	518	547	827	392	115	215	382	015	628	793	4
57	540	528	848	373	136	195	403	.71995	649	772	3
58	562	509	870	353	157	175	424	974	670	752	2
59	584	490	891	334	179	155	445	954	690	731	1
60	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	Cos.	Sin.	M.
	49°		48°		47°		46°		45°		

APPENDIX IV.—NATURAL TANGENTS AND COTANGENTS

M	0°		1°		2°		3°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.00000	0	0.01746	57.2900	0.03492	28.6363	0.05241	19.0811	60
1	029	3437.75	775	56.3506	521	.3994	270	18.9755	59
2	058	1718.87	804	55.4415	550	.1664	299	.8711	58
3	087	1145.92	833	54.5613	579	27.9372	328	.7678	57
4	116	859.436	862	53.7086	609	.7117	357	.6656	56
5	.00145	687.549	.01891	52.8821	.03638	27.4899	.05387	18.5645	55
6	175	572.957	920	52.0807	667	.2715	416	.4645	54
7	204	491.106	949	51.3032	696	.0566	445	.3655	53
8	233	429.718	978	50.5485	725	26.8450	474	.2677	52
9	262	381.971	.02007	49.8157	754	.6367	503	.1708	51
10	.00291	343.774	.02036	49.1039	.03783	26.4316	.05533	18.0750	50
11	320	312.521	066	48.4121	812	.2296	562	17.9802	49
12	349	286.478	095	47.7395	842	.0307	591	.8863	48
13	378	264.441	124	47.0853	871	25.8348	620	.7934	47
14	407	245.552	153	46.4489	900	.6418	649	.7015	46
15	.00436	229.182	.02182	45.8294	.03929	25.4517	.05678	17.6106	45
16	465	214.858	211	45.2261	958	.2644	708	.5205	44
17	495	202.219	240	44.6386	987	.0798	737	.4314	43
18	524	190.984	269	44.0661	.04016	24.8978	766	.3432	42
19	553	180.932	298	43.5081	046	.7185	795	.2558	41
20	.00582	171.885	.02328	42.9641	.04075	24.5418	.05824	17.1693	40
21	611	163.700	357	42.4335	104	.3675	854	.0837	39
22	640	156.259	386	41.9158	133	.1957	883	16.9990	38
23	669	149.465	415	41.4106	162	.0263	912	.9150	37
24	698	143.237	444	40.9174	191	23.8593	941	.8319	36
25	.00727	137.507	.02473	40.4358	.04220	23.6945	.05970	16.7496	35
26	756	132.219	502	39.9655	250	.5321	999	.6681	34
27	785	127.321	531	39.5059	279	.3718	.06020	.5874	33
28	815	122.774	560	39.0568	308	.2137	058	.5075	32
29	844	118.540	589	38.6177	337	.0577	087	.4283	31
30	.00873	114.589	.02619	38.1885	.04366	22.9038	.06116	16.3499	30
31	902	110.892	648	37.7686	395	.7519	145	.2722	29
32	931	107.426	677	37.3579	424	.6020	175	.1952	28
33	960	104.171	706	36.9560	454	.4541	204	.1190	27
34	989	101.107	735	36.5627	483	.3081	233	.0435	26
35	.01018	98.2179	.02764	36.1776	.04512	22.1640	.06262	15.9687	25
36	047	95.4895	793	35.8006	541	.0217	291	.8945	24
37	076	92.9085	822	35.4313	570	21.8813	321	.8211	23
38	105	90.4633	851	35.0695	599	.7426	350	.7483	22
39	135	88.1436	881	34.7151	628	.6056	379	.6762	21
40	.01164	85.9398	.02910	34.3678	.04658	21.4704	.06408	15.6048	20
41	193	83.8435	939	34.0273	687	.3369	438	.5340	19
42	222	81.8470	968	33.6935	716	.2049	467	.4638	18
43	251	79.9434	997	33.3662	745	.0747	496	.3943	17
44	280	78.1263	.03026	33.0452	774	20.9460	525	.3254	16
45	.01309	76.3900	.03055	32.7303	.04803	20.8188	.06554	15.2571	15
46	338	74.7292	084	32.4213	833	.6932	584	.1893	14
47	367	73.1390	114	32.1181	862	.5691	613	.1222	13
48	396	71.6151	143	31.8205	891	.4465	642	.0557	12
49	425	70.1533	172	31.5284	920	.3253	671	14.9898	11
50	.01455	68.7501	.03201	31.2416	.04949	20.2056	.06700	14.9244	10
51	484	67.4019	230	30.9599	978	.0872	730	.8596	9
52	513	66.1055	259	30.6833	.05007	19.9702	759	.7954	8
53	542	64.8580	288	30.4116	037	.8546	788	.7317	7
54	571	63.6567	317	30.1446	066	.7403	817	.6685	6
55	.01600	62.4992	.03346	29.8823	.05095	19.6273	.06847	14.6059	5
56	629	61.3829	376	29.6245	124	.5156	876	.5438	4
57	658	60.3058	405	29.3711	153	.4051	905	.4823	3
58	687	59.2659	434	29.1220	182	.2959	934	.4212	2
59	716	58.2612	463	28.8771	212	.1879	963	.3607	1
60	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	89°		88°		87°		86°		

M.	4° Tan.	4° Cot.	5° Tan.	5° Cot.	6° Tan.	6° Cot.	7° Tan.	7° Cot.	
0	0.06993	14.3007	0.08749	11.4301	0.10510	9.51436	0.12278	8.14435	60
1	.07022	.2411	778	.3919	540	.48781	308	.12481	59
2	051	.1821	807	.3540	569	.46141	338	.10536	58
3	080	.1235	837	.3163	599	.43515	367	.08600	57
4	110	.0655	866	.2789	628	.40904	397	.06674	56
5	.07139	14.0079	.08895	11.2417	.10657	9.38307	.12426	8.04756	55
6	168	13.9507	925	.2048	687	.35724	456	.02848	54
7	197	.8940	954	.1681	716	.33155	485	.00948	53
8	227	.8378	983	.1316	746	.30599	515	7.99058	52
9	256	.7821	.09013	.0954	775	.28058	544	.97176	51
10	.07285	13.7267	.09042	11.0594	.10805	9.25530	.12574	7.95302	50
11	314	.6719	071	.0237	834	.23016	603	.93438	49
12	344	.6174	101	10.9882	863	.20516	633	.91582	48
13	373	.5634	130	.9529	893	.18028	662	.89734	47
14	402	.5098	159	.9178	922	.15554	692	.87895	46
15	.07431	13.4566	.09189	10.8829	.10952	9.13093	.12722	7.86064	45
16	461	.4039	218	.8483	981	.10646	751	.84242	44
17	490	.3515	247	.8139	.11011	.08211	781	.82428	43
18	519	.2996	277	.7797	040	.05789	810	.80622	42
19	548	.2480	306	.7457	070	.03379	840	.78825	41
20	.07578	13.1969	.09335	10.7119	.11099	9.00983	.12869	7.77035	40
21	607	.1461	365	.6783	128	8.98598	899	.75254	39
22	636	.0958	394	.6450	158	.96227	929	.73480	38
23	665	.0458	423	.6118	187	.93867	958	.71715	37
24	695	12.9962	453	.5789	217	.91520	988	.69957	36
25	.07724	12.9469	.09482	10.5462	.11246	8.89185	.13017	7.68208	35
26	753	.8981	511	.5136	276	.86862	047	.66466	34
27	782	.8496	541	.4813	305	.84551	076	.64732	33
28	812	.8014	570	.4491	335	.82252	106	.63005	32
29	841	.7536	600	.4172	364	.79964	136	.61287	31
30	.07870	12.7062	.09629	10.3854	.11394	8.77689	.13165	7.59575	30
31	899	.6591	658	.3538	423	.75425	195	.57872	29
32	929	.6124	688	.3224	452	.73172	224	.56176	28
33	958	.5660	717	.2913	482	.70931	254	.54487	27
34	987	.5199	746	.2602	511	.68701	284	.52806	26
35	.08017	12.4742	.09776	10.2294	.11541	8.66482	.13313	7.51132	25
36	046	.4288	805	.1988	570	.64275	343	.49465	24
37	075	.3838	834	.1683	600	.62078	372	.47806	23
38	104	.3390	864	.1381	629	.59893	402	.46154	22
39	134	.2946	893	.1080	659	.57718	432	.44509	21
40	.08163	12.2505	.09923	10.0780	.11688	8.55555	.13461	7.42871	20
41	192	.2067	952	.0483	718	.53402	491	.41240	19
42	221	.1632	981	.0187	747	.51259	521	.39616	18
43	251	.1201	.10011	9.98931	777	.49128	550	.37999	17
44	280	.0772	040	.96007	806	.47007	580	.36389	16
45	.08309	12.0346	.10069	9.93101	.11836	8.44896	.13609	7.34786	15
46	339	11.9923	099	.90211	865	.42795	639	.33190	14
47	368	.9504	128	.87338	895	.40705	669	.31600	13
48	397	.9087	158	.84482	924	.38625	698	.30018	12
49	427	.8673	187	.81641	954	.36555	728	.28442	11
50	.08456	11.8262	.10216	9.78817	.11983	8.34496	.13758	7.26873	10
51	485	.7853	246	.76009	.12013	.32446	787	.25310	9
52	514	.7448	275	.73217	042	.30406	817	.23754	8
53	544	.7045	305	.70441	072	.28376	846	.22204	7
54	573	.6645	334	.67680	101	.26355	876	.20661	6
55	.08602	11.6248	.10363	9.64935	.12131	8.24345	.13906	7.19125	5
56	632	.5853	393	.62205	160	.22344	935	.17594	4
57	661	.5461	422	.59490	190	.20352	965	.16071	3
58	690	.5072	452	.56791	219	.18370	995	.14553	2
59	720	.4685	481	.54106	249	.16398	.14024	.13042	1
60	.08749	11.4301	.10510	9.51436	.12278	8.14435	.14054	7.11537	0
	85° Cot.	85° Tan.	84° Cot.	84° Tan.	83° Cot.	83° Tan.	82° Cot.	82° Tan.	M.

M.	8° Tan.	8° Cot.	9° Tan.	9° Cot.	10° Tan.	10° Cot.	11° Tan.	11° Cot.	
0	0. 14054	7. 11537	0. 15838	6. 31375	0. 17633	5. 67128	0. 19438	5. 14455	60
1	084	. 10038	868	. 30189	663	. 66165	468	. 13658	59
2	113	. 08546	898	. 29007	693	. 65205	498	. 12862	58
3	143	. 07059	928	. 27829	723	. 64248	529	. 12069	57
4	173	. 05579	958	. 26655	753	. 63295	559	. 11279	56
5	. 14202	7. 04105	. 15988	6. 25486	. 17783	5. 62344	. 19589	5. 10490	55
6	232	. 02637	. 16017	. 24321	813	. 61397	619	. 09704	54
7	262	. 01174	047	. 23160	843	. 60452	649	. 08921	53
8	291	6. 99718	077	. 22003	873	. 59511	680	. 08139	52
9	321	. 98268	107	. 20851	903	. 58573	710	. 07360	51
10	. 14351	6. 96823	. 16137	6. 19703	. 17933	5. 57638	. 19740	5. 06584	50
11	381	. 95385	167	. 18559	963	. 56706	770	. 05809	49
12	410	. 93952	196	. 17419	993	. 55777	801	. 05037	48
13	440	. 92525	226	. 16283	. 18023	. 54851	831	. 04267	47
14	470	. 91104	256	. 15151	053	. 53927	861	. 03499	46
15	. 14499	6. 89688	. 16286	6. 14023	. 18083	5. 53007	. 19891	5. 02734	45
16	529	. 88278	316	. 12899	113	. 52090	921	. 01971	44
17	559	. 86874	346	. 11779	143	. 51176	952	. 01210	43
18	588	. 85475	376	. 10664	173	. 50264	982	. 00451	42
19	618	. 84082	405	. 09552	203	. 49356	. 20012	4. 99695	41
20	. 14648	6. 82694	. 16435	6. 08444	. 18233	5. 48451	. 20042	4. 98940	40
21	678	. 81312	465	. 07340	263	. 47548	073	. 98188	39
22	707	. 79936	495	. 06240	293	. 46648	103	. 97438	38
23	737	. 78564	525	. 05143	323	. 45751	133	. 96690	37
24	767	. 77199	555	. 04051	353	. 44857	164	. 95945	36
25	. 14796	6. 75838	. 16585	6. 02962	. 18384	5. 43966	. 20194	4. 95201	35
26	826	. 74483	615	. 01878	414	. 43077	224	. 94460	34
27	856	. 73133	645	. 00797	444	. 42192	254	. 93721	33
28	886	. 71789	674	5. 99720	474	. 41309	285	. 92984	32
29	915	. 70450	704	. 98646	504	. 40429	315	. 92249	31
30	. 14945	6. 69116	. 16734	5. 97576	. 18534	5. 39552	. 20345	4. 91516	30
31	975	. 67787	764	. 96510	564	. 38677	376	. 90785	29
32	. 15005	. 66463	794	. 95448	594	. 37805	406	. 90056	28
33	034	. 65144	824	. 94390	624	. 36936	436	. 89330	27
34	064	. 63831	854	. 93335	654	. 36070	466	. 88605	26
35	. 15094	6. 62523	. 16884	5. 92283	. 18684	5. 35206	. 20497	4. 87882	25
36	124	. 61219	914	. 91236	714	. 34345	527	. 87162	24
37	153	. 59921	944	. 90191	745	. 33487	557	. 86444	23
38	183	. 58627	974	. 89151	775	. 32631	588	. 85727	22
39	213	. 57339	. 17004	. 88114	805	. 31778	618	. 85013	21
40	. 15243	6. 56055	. 17033	5. 87080	. 18835	5. 30928	. 20648	4. 84300	20
41	272	. 54777	063	. 86051	865	. 30080	679	. 83590	19
42	302	. 53503	093	. 85024	895	. 29235	709	. 82882	18
43	332	. 52234	123	. 84001	925	. 28398	739	. 82175	17
44	362	. 50970	153	. 82982	955	. 27553	770	. 81471	16
45	. 15391	6. 49710	. 17183	5. 81966	. 18986	5. 26715	. 20800	4. 80769	15
46	421	. 48456	213	. 80953	. 19016	. 25880	830	. 80068	14
47	451	. 47206	243	. 79944	046	. 25048	861	. 79370	13
48	481	. 45961	273	. 78938	076	. 24218	891	. 78673	12
49	511	. 44720	303	. 77936	106	. 23391	921	. 77978	11
50	. 15540	6. 43484	. 17333	5. 76937	. 10136	5. 22566	. 20952	4. 77286	10
51	570	. 42253	363	. 75941	166	. 21744	982	. 76595	9
52	600	. 41026	393	. 74949	197	. 20925	. 21013	. 75906	8
53	630	. 39804	423	. 73960	227	. 20107	043	. 75219	7
54	660	. 38587	453	. 72974	257	. 19293	073	. 74534	6
55	. 15689	6. 37374	. 17483	5. 71992	. 19287	5. 18480	. 21104	4. 73851	5
56	719	. 36165	513	. 71013	317	. 17671	134	. 73170	4
57	749	. 34961	543	. 70037	347	. 16863	164	. 72490	3
58	779	. 33761	573	. 69064	378	. 16058	195	. 71813	2
59	809	. 32566	603	. 68094	408	. 15256	225	. 71137	1
60	. 15838	6. 31375	. 17633	5. 67128	. 19438	5. 14455	. 21256	4. 70463	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	81°		80°		79°		78°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	12°		13°		14°		15°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.21256	4.70463	0.23087	4.33148	0.24933	4.01078	0.26795	3.73205	60
1	286	.69791	117	.32573	964	.00582	826	.72771	59
2	316	.69121	148	.32001	995	.00086	857	.72338	58
3	347	.68452	179	.31430	.25026	3.99592	888	.71907	57
4	377	.67786	209	.30860	056	.99099	920	.71476	56
5	.21408	4.67121	.23240	4.30291	.25087	3.98607	.26951	3.71046	55
6	438	.66458	271	.29724	118	.98117	982	.70616	54
7	469	.65797	301	.29159	149	.97627	.27013	.70188	53
8	499	.65138	332	.28595	180	.97139	044	.69761	52
9	529	.64480	363	.28032	211	.96651	076	.69335	51
10	.21560	4.63825	.23393	4.27471	.25242	3.96165	.27107	3.68909	50
11	590	.63171	424	.26911	273	.95680	138	.68485	49
12	621	.62518	455	.26352	304	.95196	169	68061	48
13	651	.61868	485	25795	335	.94713	201	.67638	47
14	682	.61219	516	.25239	366	.94232	232	.67217	46
15	.21712	4.60572	.23547	4.24685	.25397	3.93751	.27263	3.66796	45
16	743	.59927	578	.24132	428	.93721	294	.66376	44
17	773	.59283	608	.23580	459	.92793	326	.65957	43
18	804	.58641	639	.23030	490	.92316	357	.65538	42
19	834	.58001	670	.22841	521	.91839	388	.65121	41
20	.21864	4.57363	.23700	4.21933	.25552	3.91364	.27419	3.64705	40
21	895	.56726	731	.21387	583	.90890	451	.64289	39
22	925	.56091	762	.20842	614	.90417	482	.63874	38
23	956	.55458	793	.20298	645	.89945	513	.63461	37
24	986	.54826	823	.19756	676	.89474	545	.63048	36
25	.22017	4.54196	.23854	4.19215	.25707	3.89004	.27576	3.62636	35
26	047	.53568	885	.18675	738	.88536	607	.62224	34
27	078	.52941	916	.18137	769	.88068	638	.61814	33
28	108	.52316	946	.17600	800	.87601	670	.61405	32
29	139	.51693	977	.17064	831	.87136	701	.60996	31
30	.22169	4.51071	.24008	4.16530	.25862	3.86671	.27732	3.60588	30
31	200	.50451	039	.15997	893	.86208	764	.60181	29
32	231	.49832	69	.15465	924	.85745	795	.59775	28
33	261	.49215	100	.14934	955	.85284	826	.59370	27
34	292	.48600	131	.14405	986	.84824	858	.58966	26
35	.22322	4.47986	.24162	4.13877	.26017	3.84364	.27889	3.58562	25
36	353	.47374	193	.13350	048	.83906	921	.58160	24
37	383	.46764	223	.12825	079	.83449	952	.57758	23
38	414	.46155	254	.12301	110	.82992	983	.57357	22
39	444	.45548	285	.11778	141	.82537	.28015	.56957	21
40	.22475	4.44942	.24316	4.11256	.26172	3.82083	.28046	3.56557	20
41	505	.44338	347	.10736	203	.81630	077	.56159	19
42	536	.43735	377	.10216	235	.81177	109	.55761	18
43	567	.43134	408	.09699	266	.80726	140	.55364	17
44	597	.42534	439	.09182	297	.80276	172	.54968	16
45	.22628	4.41936	.24470	4.08666	.26328	3.79827	.28203	3.54573	15
46	658	.41340	501	.08152	359	.79378	234	.54179	14
47	689	.40745	532	.07639	390	.78931	266	.53785	13
48	719	.40152	562	.07127	421	.78485	297	.53393	12
49	750	.39560	593	.06616	452	.78040	329	.53001	11
50	.22781	4.38969	.24624	4.06107	.26483	3.77595	.28360	3.52609	10
51	811	.38381	655	.05599	515	.77152	391	.52219	9
52	842	.37793	686	.05092	546	.76709	423	.51829	8
53	872	.37207	717	.04586	577	.76268	454	.51441	7
54	903	.36623	747	.04081	608	.75828	486	.51053	6
55	.22934	4.36040	.24778	4.03578	.26639	3.75388	.28517	3.50666	5
56	964	.35459	809	.03076	670	.74950	549	.50279	4
57	995	.34879	840	.02574	701	.74512	580	.49894	3
58	.23026	.34300	871	.02074	733	.74075	612	.49509	2
59	056	.33723	902	.01576	764	.73640	643	.49125	1
60	.23087	4.33148	.24933	4.01078	.26795	3.73205	.28675	3.48741	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	77°		76°		75°		74°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	16°		17°		18°		19°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.28675	3.48741	0.30573	3.27085	0.32492	3.07768	0.34433	2.90421	60
1	706	.48359	605	.26745	524	.07464	465	.90147	59
2	738	.47927	637	.26406	556	.07160	498	.89873	58
3	769	.47596	669	.26067	588	.06857	530	.89600	57
4	801	.47216	700	.25729	621	.06554	563	.89327	56
5	.28832	3.46837	.30732	3.25392	.32653	3.06252	.34596	2.89055	55
6	864	.46458	764	.25055	685	.05950	628	.88783	54
7	896	.46080	796	.24719	717	.05649	661	.88511	53
8	927	.45705	828	.24383	749	.05349	693	.88240	52
9	958	.45327	860	.24049	782	.05049	726	.87970	51
10	.28990	3.44951	.30891	3.23714	.32814	3.04749	.34758	2.87700	50
11	.29021	.44576	923	.23381	846	.04450	791	.87430	49
12	053	.44202	955	.23048	878	.04152	824	.87161	48
13	084	.43829	987	.22715	911	.03854	856	.86892	47
14	116	.43456	.31019	.22384	943	.03556	889	.86624	46
15	.29147	3.43084	.31051	3.22053	.32975	3.03260	.34922	2.86356	45
16	179	.42713	083	.21722	.33007	.02963	954	.86089	44
17	210	.42343	115	.21392	040	.02607	987	.85822	43
18	242	.41973	147	.21063	072	.02372	.35020	.85555	42
19	274	.41604	178	.20734	104	.02077	052	.85289	41
20	.29305	3.41236	.31210	3.20406	.33136	3.01783	.35085	2.85023	40
21	337	.40869	242	.20079	169	.01489	118	.84758	39
22	368	.40502	274	.19752	201	.01196	150	.84494	38
23	400	.40136	300	.19426	233	.00903	183	.84229	37
24	432	.39771	338	.19100	266	.00611	216	.83965	36
25	.29463	3.39406	.31370	3.18775	.33298	3.00319	.35248	2.83702	35
26	495	.39042	402	.18451	330	.00028	281	.83439	34
27	526	.38679	434	.18127	363	2.99738	314	.83176	33
28	558	.38317	466	.17804	395	.99447	346	.82914	32
29	590	.37955	498	.17481	427	.99158	379	.82653	31
30	.29621	3.37594	.31530	3.17159	.33460	2.98868	.35412	2.82391	30
31	653	.37234	562	.16838	492	.98560	445	.82130	29
32	685	.36875	594	.16517	524	.98292	477	.81870	28
33	716	.36516	626	.16197	557	.98004	510	.81610	27
34	748	.36158	658	.15877	589	.97717	543	.81350	26
35	.29780	3.35800	.31690	3.15558	.33621	2.97430	.35576	2.81091	25
36	811	.35443	722	.15140	654	.97144	608	.80633	24
37	843	.35087	754	.14922	686	.96858	641	.80574	23
38	875	.34732	786	.14605	718	.96573	674	.80316	22
39	906	.34377	818	.14288	751	.96288	707	.80059	21
40	.29938	3.34023	.31850	3.13972	.33783	2.96004	.35740	2.79802	20
41	970	.33670	882	.13656	816	.95721	772	.79545	19
42	.30001	.33317	914	.13341	848	.95437	805	.79289	18
43	033	.32965	946	.13027	881	.95155	838	.79033	17
44	065	.32614	978	.12713	913	.94872	871	.78778	16
45	.30097	3.32264	.32010	3.12400	.33945	2.94591	.35904	2.78523	15
46	128	.31914	042	.12087	978	.94309	937	.78269	14
47	160	.31565	074	.11775	.34010	.94028	969	.78014	13
48	192	.31216	106	.11464	043	.93748	.36002	.77761	12
49	224	.30868	139	.11153	075	.93468	035	.77507	11
50	.30255	3.30521	.32171	3.10842	.34108	2.93189	.36068	2.77254	10
51	287	.30174	203	.10532	140	.92910	101	.77002	9
52	319	.29829	235	.10223	173	.92632	134	.76750	8
53	351	.29483	267	.09914	205	.92354	167	.76498	7
54	382	.29139	299	.09606	238	.92076	199	.76247	6
55	.30414	3.28795	.32331	3.09298	.34270	2.91799	.36232	2.75996	5
56	446	.28452	363	.08991	303	.91523	265	.75746	4
57	478	.28109	396	.08685	335	.91246	298	.75496	3
58	509	.27767	428	.08379	368	.90971	331	.75246	2
59	541	.27426	460	.08073	400	.90696	364	.74997	1
60	.30573	3.27085	.32492	3.07768	.34433	2.90421	.36397	2.74748	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	73°		72°		71°		70°		

M.	12°		13°		14°		15°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.21256	4.70463	0.23087	4.33158	0.24933	4.01078	0.26795	3.73205	60
1	286	.69791	117	.32573	964	.00582	826	.72771	59
2	316	.69121	148	.32001	995	.00086	857	.72338	58
3	347	.68452	179	.31430	.25026	3.99592	888	.71907	57
4	377	.67786	209	.30860	056	.99099	920	.71476	56
5	.21408	4.67121	.23240	4.30291	.25087	3.98607	.26951	3.71046	55
6	438	.66458	271	.29724	118	.98117	982	.70616	54
7	469	.65797	301	.29159	149	.97627	.27013	.70188	53
8	499	.65138	332	.28595	180	.97139	044	.69761	52
9	529	.64480	363	.28032	211	.96651	076	.69335	51
10	.21560	4.63825	.23393	4.27471	.25242	3.96165	.27107	3.68909	50
11	590	.63171	424	.26911	273	.95680	138	.68485	49
12	621	.62518	455	.26352	304	.95196	169	68061	48
13	651	.61868	485	25795	335	.94713	201	.67638	47
14	682	.61219	516	.25239	366	.94232	232	.67217	46
15	.21712	4.00572	.23547	4.24685	.25397	3.93751	.27263	3.66796	45
16	743	.59927	578	.24132	428	.93721	294	.66376	44
17	773	.59283	608	.23580	459	.92793	326	.65957	43
18	804	.58641	639	.23030	490	.92316	357	.65538	42
19	834	.58001	670	.22841	521	.91839	388	.65121	41
20	.21864	4.57363	.23700	4.21933	.25552	3.91364	.27419	3.64705	40
21	895	.56726	731	.21387	583	.90890	451	.64289	39
22	925	.56091	762	.20842	614	.90417	482	.63874	38
23	956	.55458	793	.20298	645	.89945	513	.63461	37
24	986	.54826	823	.19756	676	.89474	545	.63048	36
25	.22017	4.54196	.23854	4.19215	.25707	3.89004	.27576	3.62636	35
26	047	.53568	885	.18675	738	.88536	607	.62224	34
27	078	.52941	916	.18137	769	.88068	638	.61814	33
28	108	.52316	946	.17600	800	.87601	670	.61405	32
29	139	.51693	977	.17064	831	.87136	701	.60996	31
30	.22169	4.51071	.24008	4.16530	.25862	3.86671	.27732	3.60588	30
31	200	.50451	039	.15997	893	.86208	764	.60181	29
32	231	.49832	69	.15465	924	.85745	795	.59775	28
33	261	.49215	100	.14934	955	.85284	826	.59370	27
34	292	.48600	131	.14405	986	.84824	858	.58966	26
35	.22322	4.47986	.24162	4.13877	.26017	3.84364	.27889	3.58562	25
36	353	.47374	193	.13350	048	.83906	921	.58160	24
37	383	.46764	223	.12825	079	.83449	952	.57758	23
38	414	.46155	254	.12301	110	.82992	983	.57357	22
39	444	.45548	285	.11778	141	.82537	.28015	.56957	21
40	.22475	4.44942	.24316	4.11256	.26172	3.82083	.28046	3.56557	20
41	505	.44338	347	.10736	203	.81630	077	.56159	19
42	536	.43735	377	.10216	235	.81177	109	.55761	18
43	567	.43134	408	.09699	266	.80726	140	.55364	17
44	597	.42534	439	.09182	297	.80276	172	.54968	16
45	.22628	4.41936	.24470	4.08666	.26328	3.79827	.28203	3.54573	15
46	658	.41340	501	.08152	359	.79378	234	.54179	14
47	689	.40745	532	.07639	390	.78931	266	.53785	13
48	719	.40152	562	.07127	421	.78485	297	.53393	12
49	750	.39560	593	.06616	452	.78040	329	.53001	11
50	.22781	4.38969	.24624	4.06107	.26483	3.77595	.28360	3.52609	10
51	811	.38381	655	.05599	515	.77152	391	.52219	9
52	842	.37793	686	.05092	546	.76709	423	.51829	8
53	872	.37207	717	.04586	577	.76268	454	.51441	7
54	903	.36623	747	.04081	608	.75828	486	.51053	6
55	.22934	4.36040	.24778	4.03578	.26639	3.75388	.28517	3.50666	5
56	964	.35459	809	.03076	670	.74950	549	.50279	4
57	995	.34879	840	.02574	701	.74512	580	.49894	3
58	.23026	.34300	871	.02074	733	.74075	612	.49509	2
59	056	.33723	902	.01576	764	.73640	643	.49125	1
60	.23087	4.33148	.24933	4.01078	.26795	3.73205	.28675	3.48741	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	77°		76°		75°		74°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	16°		17°		18°		19°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.28675	3.48741	0.30573	3.27085	0.32492	3.07768	0.34433	2.90421	60
1	706	.48359	605	.26745	524	.07464	465	.90147	59
2	738	.47927	637	.26406	556	.07160	498	.89873	58
3	769	.47596	669	.26067	588	.06857	530	.89600	57
4	801	.47216	700	.25729	621	.06554	563	.89327	56
5	.28832	3.46837	.30732	3.25392	.32653	3.06252	.34596	2.89055	55
6	864	.46458	764	.25055	685	.05950	628	.88783	54
7	896	.46080	796	.24719	717	.05649	661	.88511	53
8	927	.45705	828	.24383	749	.05349	693	.88240	52
9	958	.45327	860	.24049	782	.05049	726	.87970	51
10	.28990	3.44951	.30891	3.23714	.32814	3.04749	.34758	2.87700	50
11	.29021	.44576	923	.23381	846	.04450	791	.87430	49
12	053	.44202	955	.23048	878	.04152	824	.87161	48
13	084	.43829	987	.22715	911	.03854	856	.86892	47
14	116	.43456	.31019	.22384	943	.03556	889	.86624	46
15	.29147	3.43084	.31051	3.22053	.32975	3.03260	.34922	2.86356	45
16	179	.42713	083	.21722	.33007	.02963	954	.86089	44
17	210	.42343	115	.21392	040	.02667	987	.85822	43
18	242	.41973	147	.21063	072	.02372	.35020	.85555	42
19	274	.41604	178	.20734	104	.02077	052	.85289	41
20	.29305	3.41236	.31210	3.20406	.33136	3.01783	.35085	2.85023	40
21	337	.40869	242	.20079	169	.01489	118	.84758	39
22	368	.40502	274	.19752	201	.01196	150	.84494	38
23	400	.40136	300	.19426	233	.00903	183	.84229	37
24	432	.39771	338	.19100	266	.00611	216	.83965	36
25	.29463	3.39406	.31370	3.18775	.33298	3.00319	.35248	2.83702	35
26	495	.39042	402	.18451	330	.00028	281	.83439	34
27	526	.38679	434	.18127	363	2.99738	314	.83176	33
28	558	.38317	466	.17804	395	.99447	346	.82914	32
29	590	.37955	498	.17481	427	.99158	379	.82653	31
30	.29621	3.37594	.31530	3.17159	.33460	2.98868	.35412	2.82391	30
31	653	.37234	562	.16838	492	.98560	445	.82130	29
32	685	.36875	594	.16517	524	.98292	477	.81870	28
33	716	.36516	626	.16197	557	.98004	510	.81610	27
34	748	.36158	658	.15877	589	.97717	543	.81350	26
35	.29780	3.35800	.31690	3.15558	.33621	2.97430	.35576	2.81091	25
36	811	.35443	722	.15140	654	.97144	608	.80633	24
37	843	.35087	754	.14922	686	.96858	641	.80574	23
38	875	.34732	786	.14605	718	.96573	674	.80316	22
39	906	.34377	818	.14288	751	.96288	707	.80059	21
40	.29938	3.34023	.31850	3.13972	.33783	2.96004	.35740	2.79802	20
41	970	.33670	882	.13656	816	.95721	772	.79545	19
42	.30001	.33317	914	.13341	848	.95437	805	.79289	18
43	033	.32965	946	.13027	881	.95155	838	.79033	17
44	065	.32614	978	.12713	913	.94872	871	.78778	16
45	.30097	3.32264	.32010	3.12400	.33945	2.94591	.35904	2.78523	15
46	128	.31914	042	.12087	978	.94309	937	.78269	14
47	160	.31565	074	.11775	.34010	.94028	969	.78014	13
48	192	.31216	106	.11464	043	.93748	.36002	.77761	12
49	224	.30868	139	.11153	075	.93468	035	.77507	11
50	.30255	3.30521	.32171	3.10842	.34108	2.93189	.36068	2.77254	10
51	287	.30174	203	.10532	140	.92910	101	.77002	9
52	319	.29829	235	.10223	173	.92632	134	.76750	8
53	351	.29483	267	.09914	205	.92354	167	.76498	7
54	382	.29139	299	.09606	238	.92076	199	.76247	6
55	.30414	3.28795	.32331	3.09298	.34270	2.91799	.36232	2.75996	5
56	446	.28452	363	.08991	303	.91523	265	.75746	4
57	478	.28109	396	.08685	335	.91246	298	.75496	3
58	509	.27767	428	.08379	368	.90971	331	.75246	2
59	541	.27426	460	.08073	400	.90696	364	.74997	1
60	.30573	3.27085	.32492	3.07768	.34433	2.90421	.36397	2.74748	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	73°		72°		71°		70°		

M.	20° Tan.	20° Cot.	21° Tan.	21° Cot.	22° Tan.	22° Cot.	23° Tan.	23° Cot.	
0	0.36397	2.74748	0.38386	2.60509	0.40403	2.47509	0.42447	2.35585	60
1	430	.74499	420	.60283	436	.47302	482	.35395	59
2	463	.74251	453	.60057	470	.47095	516	.35205	58
3	496	.74004	487	.59831	504	.46888	551	.35015	57
4	529	.73756	520	.59606	538	.46682	585	.34825	56
5	.36562	2.73509	.38553	2.59381	.40572	2.46476	.42619	2.34636	55
6	595	.73263	587	.59156	606	.46270	654	.34447	54
7	628	.73017	620	.58932	640	.46065	688	.34258	53
8	661	.72771	654	.58708	674	.45860	722	.34069	52
9	694	.72526	687	.58484	707	.45655	757	.33881	51
10	.36727	2.72281	.38721	2.58261	.40741	2.45451	.42791	2.33693	50
11	760	.72036	754	.58038	775	.45246	826	.33505	49
12	793	.71792	787	.57815	809	.45043	860	.33317	48
13	826	.71548	821	.57593	843	.44839	894	.33130	47
14	859	.71305	854	.57371	877	.44636	929	.32943	46
15	.36892	2.71062	.38888	2.57150	.40911	2.44433	.42963	2.32756	45
16	925	.70819	921	.56928	945	.44230	998	.32570	44
17	958	.70577	955	.56707	979	.44027	.43032	.32383	43
18	991	.70335	988	.56487	.41013	.43825	067	.32197	42
19	.37024	.70094	.39022	.56266	047	.43623	101	.32012	41
20	.37057	2.69853	.39055	2.56046	.41081	2.43422	.43136	2.31826	40
21	090	.69612	089	.55827	115	.43220	170	.31641	39
22	123	.69371	122	.55608	149	.43019	205	.31456	38
23	157	.69131	156	.55389	183	.42819	239	.31271	37
24	190	.68892	190	.55170	217	.42618	274	.31086	36
25	.37223	2.68653	.39223	2.54952	.41251	2.42418	.43308	2.30902	35
26	256	.68414	257	.54734	285	.42218	343	.30718	34
27	289	.68175	290	.54516	319	.42019	378	.30534	33
28	322	.67937	324	.54299	353	.41819	412	.30351	32
29	355	.67700	357	.54082	387	.41620	447	.30167	31
30	.37388	2.67462	.39391	2.53865	.41421	2.41421	.43481	2.29984	30
31	422	.67225	425	.53648	455	.41223	516	.29801	29
32	455	.66989	458	.53432	490	.41025	550	.29619	28
33	488	.66752	492	.53217	524	.40827	585	.29437	27
34	521	.66516	526	.53001	558	.40629	620	.29254	26
35	.37554	2.66281	.39559	2.52786	.41592	2.40432	.43654	2.29073	25
36	588	.66046	593	.52571	626	.40235	689	.28891	24
37	621	.65811	626	.52357	660	.40038	724	.28710	23
38	654	.65576	660	.52142	694	.39841	758	.28528	22
39	687	.65342	694	.51929	728	.39645	793	.28348	21
40	.37720	2.65109	.39727	2.51715	.41763	2.39449	.43828	2.28167	20
41	754	.64875	761	.51502	797	.39253	862	.27987	19
42	787	.64642	795	.51289	831	.39058	897	.27806	18
43	820	.64410	829	.51076	865	.38863	932	.27626	17
44	853	.64177	862	.50864	899	.38668	966	.27447	16
45	.37887	2.63945	.39896	2.50652	.41933	2.38473	.44001	2.27267	15
46	920	.63714	930	.50440	968	.38279	036	.27088	14
47	953	.63483	963	.50229	.42002	.38084	071	.26909	13
48	986	.63252	997	.50018	036	.37891	105	.26730	12
49	.38020	.63021	.40031	.49807	070	.37697	140	.26552	11
50	.38053	2.62791	.40065	2.49597	.42105	2.37594	.44175	2.26374	10
51	086	.62561	098	.49386	139	.37311	210	.26196	9
52	120	.62332	132	.49177	173	.37118	244	.26018	8
53	153	.62103	166	.48967	207	.36925	279	.25840	7
54	186	.61874	200	.48758	242	.36733	314	.25663	6
55	.38220	2.61646	.40234	2.48549	.42276	2.36541	.44349	2.25486	5
56	253	.61418	267	.48340	310	.36349	384	.25309	4
57	286	.61190	301	.48132	345	.36158	418	.25132	3
58	320	.60963	335	.47924	379	.35967	453	.24956	2
59	353	.60736	369	.47716	413	.35776	488	.24780	1
60	.38386	2.60509	.40403	2.47509	.42447	2.35585	.44523	2.24604	0
	69° Cot.	69° Tan.	68° Cot.	68° Tan.	67° Cot.	67° Tan.	66° Cot.	66° Tan.	M.

M.	24°		25°		26°		27°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.44523	2,24604	0,46631	2.14451	0.48773	2.05030	0.50953	1.96261	60
1	558	.24428	666	14288	809	.04879	989	.96120	59
2	593	.24252	702	.14125	845	.04728	.51026	.95979	58
3	627	.24077	737	.13963	881	.04577	063	.95838	57
4	662	.23902	772	.13801	917	.04426	099	.95698	56
5	.44697	2.23727	.46908	2.13639	.48953	2.04276	.51136	1,95557	55
6	732	.23553	843	.13477	989	.04125	173	.95417	54
7	767	.23378	879	.13316	.49026	.03975	209	.95277	53
8	802	.23204	914	.13154	062	.03825	246	.95137	52
9	837	.23030	950	.12993	098	.03675	283	.94997	51
10	.44872	2.22857	46985	2,12832	.49134	2.03526	.51319	1,94858	50
11	907	.22683	.47021	.12671	170	.03376	356	.94718	49
12	942	.22510	056	.12511	206	.03227	393	.94579	48
13	977	.22337	092	.12350	242	.03078	430	.94440	47
14	.45012	.22164	128	.12190	278	.02929	467	.94301	46
15	.45047	2.21992	.47163	2.12030	.49315	2.02780	.51503	1.94162	45
16	082	.21819	199	.11871	351	.02631	540	.94023	44
17	117	.21647	234	.11711	387	.02483	577	.93885	43
18	152	.21475	270	.11552	423	.02335	614	.93746	42
19	187	.21304	305	.11392	459	.02187	651	.93608	41
20	.45222	2.21132	.47341	2.11233	.49495	2.02039	.51688	1,93470	40
21	257	.20961	377	.11075	532	.01891	724	.93332	39
22	292	.20790	412	.10916	568	.01743	761	.93195	38
23	327	.20619	448	.10758	604	.01596	798	.93057	37
24	362	.20449	483	.10600	640	.01499	835	.92920	36
25	.45397	2.20278	.47519	2.10442	.49677	2.01302	.51872	1.92782	35
26	432	.20108	555	.10284	713	.01155	909	.92645	34
27	467	.19938	590	.10126	749	.01008	946	.92508	33
28	502	.19769	626	.09969	786	.00862	983	.92371	32
29	538	.19599	662	.09811	822	.00715	.52020	.92235	31
30	.45573	2.19430	.47698	2.09654	.49858	2.00569	.52057	1.92098	30
31	608	.19261	733	.09498	894	.00423	094	.91962	29
32	643	.19092	769	.09341	931	.00277	131	.91826	28
33	678	.18923	805	.09184	967	.00131	168	.91690	27
34	713	.18755	840	.09028	.50004	1.99986	205	.91554	26
35	.45748	2.18587	.47876	2.08872	.50040	1.99841	.52242	1,91418	25
36	784	.18419	912	.08716	076	.99695	279	.91282	24
37	819	.18251	948	.08560	113	.99550	316	.91147	23
38	854	.18084	984	.08405	149	.99406	353	.91012	22
39	889	.17916	.48019	08250	185	.99261	390	.90876	21
40	.45924	2.17749	.48055	2.08094	.50222	1.99116	.52427	1,90741	20
41	960	.17582	001	.07939	258	.98972	464	.90607	19
42	995	.17416	127	.07785	295	.98828	501	.90472	18
43	.46030	.17249	163	.07630	331	.98684	538	.90337	17
44	065	.17083	198	.07476	368	.98540	575	.90203	16
45	.46101	2.16917	.48234	2.07321	.50404	1.98396	.52613	1,90069	15
46	136	.16751	270	.07167	441	.98253	650	.89935	14
47	171	.16585	306	.07014	477	.98110	687	.89801	13
48	206	.16420	342	.06860	514	.97066	724	.89667	12
49	242	.16255	378	.06706	550	.97823	761	.89533	11
50	.46277	2.16090	.48414	2.06553	.50587	1.97681	.52798	1,89400	10
51	312	.15925	450	.06400	623	.97538	836	.89266	9
52	348	.15760	486	.06247	660	.97395	873	.89133	8
53	383	.15596	521	.06094	696	.97253	910	.89000	7
54	418	.15432	557	.05942	733	.97111	947	.88867	6
55	.46454	2.15268	.48593	2,05790	.50769	1,96969	.52985	1.88734	5
56	489	.15104	629	.05637	806	.96827	.53022	.88602	4
57	525	.14940	665	.05485	843	.96685	059	.88469	3
58	560	.14777	701	.05333	879	.96544	096	.88337	2
59	595	.14614	737	.05182	916	.96402	134	.88205	1
60	.46631	2.14451	.48773	2.05030	.50953	1,96261	.53171	1,88073	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	65°		64°		63°		62°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	28°		29°		30°		31°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.53171	1.88073	0.55431	1.80405	0.57735	1.73205	0.60086	1.66428	60
1	208	.87941	469	.80281	774	.73089	126	.66318	59
2	246	.87809	507	.80158	813	.72973	165	.66209	58
3	283	.87677	545	.80034	851	.72857	205	.66099	57
4	320	.87546	583	.79911	890	.72741	245	.65990	56
5	.53358	1.87415	.55621	1.79788	.57929	1.72625	.60284	1.65881	55
6	395	.87283	659	.79665	968	.72509	324	.65772	54
7	432	.87152	697	.79542	.58007	.72393	364	.65663	53
8	470	.87021	736	.79419	046	.72278	403	.65554	52
9	507	.86891	774	.79296	085	.72163	443	.65445	51
10	.53545	1.86760	.55812	1.79174	.58124	1.72047	.60483	1.65337	50
11	582	.86630	850	.79051	162	.71932	522	.65228	49
12	620	.86499	888	.78929	201	.71817	562	.65120	48
13	657	.86369	926	.78807	240	.71702	602	.65011	47
14	694	.86239	964	.78685	279	.71588	642	.64903	46
15	.53732	1.86109	56003	1.78563	.58318	1.71473	.60681	1.64795	45
16	769	.85979	041	.78441	357	.71358	721	.64687	44
17	807	.85850	079	.78319	396	.71244	761	.64579	43
18	844	.85720	117	.78198	435	.71129	801	.64471	42
19	882	.85591	156	.78077	474	.71015	841	.64363	41
20	.53920	1.85462	.56194	1.77955	.58513	1.70901	.60881	1.64256	40
21	957	.85333	232	.77834	552	.70787	921	.64148	39
22	995	.85204	270	.77713	591	.70673	960	.64041	38
23	.54032	.85075	309	.77592	631	.70560	.61000	.63934	37
24	070	.84946	347	.77471	670	.70446	040	.63826	36
25	.54107	1.84818	.56385	1.77351	.58709	1.70332	.61080	1.63719	35
26	145	.84689	424	.77230	748	.70219	120	.63612	34
27	183	.84561	462	.77110	787	.70106	160	.63505	33
28	220	.84433	501	.76990	826	.69992	200	.63398	32
29	258	.84305	539	.76869	865	.69879	240	.63292	31
30	.54296	1.84177	.56577	1.76749	.58905	1.69766	.61280	1.63185	30
31	333	.84049	616	.76629	944	.69653	320	.63079	29
32	371	.83922	654	.76510	983	.69541	360	.62972	28
33	409	.83794	693	.76390	.59022	.69428	400	.62866	27
34	446	.83667	731	.76271	061	.69316	440	.62760	26
35	.54484	1.83540	.56769	1.76151	.59101	1.69203	.61480	1.62654	25
36	522	.83413	808	.76032	140	.69091	520	.62548	24
37	560	.83286	846	.75913	179	.68979	561	.62442	23
38	597	.83159	885	.75794	218	.68866	601	.62336	22
39	635	.83033	923	.75675	258	.68754	641	.62230	21
40	.54673	1.82906	.56962	1.75556	.59297	1.68643	.61681	1.62125	20
41	711	.82780	.57000	.75437	336	.68531	721	.62019	19
42	748	.82654	039	.75319	376	.68419	761	.61914	18
43	786	.82528	078	.75200	415	.68308	801	.61808	17
44	824	.82402	116	.75082	454	.68196	842	.61703	16
45	.54862	1.82276	.57155	1.74964	.59494	1.68085	.61882	1.61598	15
46	900	.82150	193	.74846	533	.67974	922	.61493	14
47	938	.82025	232	.74728	573	.67863	962	.61388	13
48	975	.81899	271	.74610	612	.67752	.62003	.61283	12
49	.55013	.81774	309	.74492	651	.67641	043	.61179	11
50	.55051	1.81649	.57348	1.74375	.59691	1.67530	.62083	1.61074	10
51	089	.81524	386	.74257	730	.67419	124	.60970	9
52	127	.81399	425	.74140	770	.67309	164	.60865	8
53	165	.81274	464	.74022	809	.67198	204	.60761	7
54	203	.81150	503	.73905	849	.67088	245	.60657	6
55	.55241	1.81025	.57541	1.73788	.59888	1.66978	.62285	1.60553	5
56	279	.80901	580	.73671	928	.66867	325	.60449	4
57	317	.80777	619	.73555	967	.66757	366	.60345	3
58	355	.80653	657	.73438	.60007	.66647	406	.60241	2
59	393	.80529	696	.73321	046	.66538	446	.60137	1
60	.55431	1.80405	.57735	1.73205	.60086	1.66428	.62487	1.60033	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	61°		60°		59°		58°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	32°		33°		34°		35°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.62487	1.60033	0.64941	1.53986	0.67451	1.48256	0.70021	1.42815	60
1	527	.59930	982	.53888	493	.48163	064	.42726	59
2	568	.59826	.65024	.53791	536	.48070	107	.42638	58
3	608	.59723	065	.53693	578	.47977	151	.42550	57
4	649	.59620	106	.53595	620	.47885	194	.42462	56
5	.62689	1.59517	.65148	1.53497	.67663	1.47792	.70238	1.42374	55
6	730	.59414	189	.53400	705	.47699	281	.42286	54
7	770	.59311	231	.53302	748	.47607	325	.42198	53
8	811	.59208	272	.53205	790	.47514	368	.42110	52
9	. 852	.59105	314	.53107	832	.47422	412	.42022	51
10	.62892	1.59002	.65355	1.53010	.67875	1.47330	.70455	1.41934	50
11	933	.58900	397	.52913	917	.47238	499	.41847	49
12	973	.58797	438	.52816	960	.47146	542	.41759	48
13	.63014	.58695	480	.52719	.68002	.47053	586	.41672	47
14	055	.58593	521	.52622	045	.46962	629	.41584	46
15	.63095	1.58490	.65563	1.52525	.68088	1.46870	.70673	1.41497	45
16	136	.58388	604	.52429	130	.46778	717	.41409	44
17	177	.58286	646	.52332	173	.46686	760	.41322	43
18	217	.58184	688	.52235	215	.46595	804	.41235	42
19	258	.58083	729	.52139	258	.46503	848	.41148	41
20	.63299	1.57981	.65771	1.52043	.68301	1.46411	.70891	1.41061	40
21	340	.57879	813	.51946	343	.46320	935	.40974	39
22	380	.57778	854	.51850	386	.46229	979	.40887	38
23	421	.57676	896	.51754	429	.46137	.71023	.40800	37
24	462	.57575	938	.51658	471	.46046	066	.40714	36
25	.63503	1.57474	.65980	1.51562	.68514	1.45955	.71110	1.40627	35
26	544	.57372	.66021	.51466	557	.45864	154	.40540	34
27	584	.57271	063	.51370	600	.45773	198	.40454	33
28	625	.57170	105	.51275	642	.45682	242	.40367	32
29	666	.57069	147	.51179	685	.45592	285	.40281	31
30	.63707	1.56969	.66189	1.51084	.68728	1.45501	.71329	1.40195	30
31	748	.56868	230	.50988	771	.45410	373	.40109	29
32	789	.56767	272	.50893	814	.45320	417	.40022	28
33	830	.56667	314	.50797	857	.45229	461	.39936	27
34	871	.56566	356	.50702	900	.45139	505	.39850	26
35	.63912	1.56466	.66398	1.50607	.68942	1.45049	.71549	1.39764	25
36	953	.56366	440	.50512	985	.44958	593	.39679	24
37	994	.56265	482	.50417	.69028	.44868	637	.39593	23
38	.64035	.56165	524	.50322	071	.44778	681	.39507	22
39	076	.56065	566	.50228	114	.44688	725	.39421	21
40	.64117	1.55966	.66608	1.50133	.69157	1.44598	.71769	1.39336	20
41	158	.55866	650	.50038	200	.44508	813	.39250	19
42	199	.55766	692	.49944	243	.44418	857	.39165	18
43	240	.55666	734	.49849	286	.44329	901	.39079	17
44	281	.55567	776	.49755	329	.44239	946	.38994	16
45	.64322	1.55467	.66818	1.49661	.69372	1.44149	.71990	1.38909	15
46	363	.55368	860	.49566	416	.44060	.72034	.38824	14
47	404	.55269	902	.49472	459	.43970	078	.38738	13
48	446	.55170	944	.49378	502	.43881	122	.38653	12
49	487	.55071	986	.49284	545	.43792	167	.38568	11
50	.64528	1.54972	.67028	1.49190	.69588	1.43703	.72211	1.38484	10
51	569	.54873	071	.49097	631	.43614	255	.38399	9
52	610	.54774	113	.49003	675	.43525	299	.38314	8
53	652	.54675	155	.48909	718	.43436	344	.38229	7
54	693	.54576	197	.48816	761	.43347	388	.38145	6
55	.64734	1.54478	.67239	1.48722	.69804	1.43258	.72432	1.38060	5
56	775	.54379	282	.48629	847	.43169	477	.37976	4
57	817	.54281	324	.48536	891	.43080	521	.37891	3
58	858	.54183	366	.48442	934	.42992	565	.37807	2
59	899	.54085	409	.48349	977	.42903	610	.37722	1
60	.64941	1.53986	.67451	1.48256	.70021	1.42815	.72654	1.37638	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	57°		56°		55°		54°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	36°		37°		38°		39°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.72654	1.37638	0.75355	1.32704	0.78129	1.2794	0.80978	1.23490	60
1	699	.37554	401	.32624	175	.27917	.81027	.23416	59
2	743	.37470	447	.32544	222	.27841	075	.23343	58
3	788	.37386	492	.32464	269	.27764	123	.23270	57
4	832	.37302	538	.32384	316	.27688	171	.23196	56
5	.72877	1.37218	.75584	1.32304	.78363	1.27611	.81220	1.23123	55
6	921	.37134	629	.32224	410	.27535	268	.23050	54
7	966	.37050	675	.32144	457	.27458	316	.22977	53
8	.73010	.36967	721	.32064	504	.27382	364	.22904	52
9	055	.36883	767	.31984	551	.27306	413	.22831	51
10	.73100	1.36800	.75812	1.31904	.78598	1.27230	.81461	1.22758	50
11	144	.36716	858	.31825	645	.27153	510	.22685	49
12	189	.36633	904	.31745	692	.27077	558	.22612	48
13	234	.36549	950	.31666	739	.27001	606	.22539	47
14	278	.36466	996	.31586	786	.26925	655	.22467	46
15	.73323	1.36383	.76042	1.31507	.78834	1.26849	.81703	1.22394	45
16	368	.36300	088	.31427	881	.26774	752	.22321	44
17	413	.36217	134	.31348	928	.26698	800	.22249	43
18	457	.36134	180	.31269	975	.26622	849	.22176	42
19	502	.36051	226	.31190	.79022	.26546	898	.22104	41
20	.73547	1.35968	.76272	1.31110	.79070	1.26471	.81946	1.22031	40
21	592	.35885	318	.31031	117	.26395	995	.21959	39
22	637	.35802	364	.30952	164	.26319	.82044	.21886	38
23	681	.35719	410	.30873	212	.26244	092	.21814	37
24	726	.35637	456	.30795	259	.26169	141	.21742	36
25	.73771	1.3554	.76502	1.30716	.79306	1.26093	.82190	1.21670	35
26	816	.35472	548	.30637	354	.26018	238	.21598	34
27	861	.35389	594	.30558	401	.25943	287	.21526	33
28	906	.35307	640	.30480	449	.25867	336	.21454	32
29	951	.35244	686	.30401	496	.25792	385	.21382	31
30	.73996	1.35142	.76733	1.30323	.79544	1.25717	.82434	1.21310	30
31	.74041	.35060	779	.30244	591	.25642	483	.21238	29
32	086	.34978	825	.30166	639	.25567	531	.21166	28
33	131	.34896	871	.30087	686	.25492	580	.21094	27
34	176	.34814	918	.30009	734	.25417	629	.21023	26
35	.74221	1.34732	.76964	1.29931	.79781	1.25343	.82678	1.20951	25
36	267	.34650	.77010	.29853	829	.25268	727	.20879	24
37	312	.34568	057	.29775	877	.25193	776	.20808	23
38	357	.34487	103	.29696	924	.25118	825	.20736	22
39	402	.34405	149	.29618	972	.25044	874	.20665	21
40	.74447	1.34323	.77196	1.29541	.80020	1.24969	.82923	1,20593	20
41	492	.34242	242	.29463	067	.24895	972	.20522	19
42	538	.34160	289	.29385	115	.21820	.83022	.20451	18
43	533	.34079	335	.29307	163	.24746	071	.20379	17
44	628	.33998	382	.29229	211	.24672	120	.20308	16
45	.74674	1.33916	.77428	1.29152	.80258	1.24597	.83169	1.20237	15
46	719	.33835	475	.29074	306	.24523	218	.20166	14
47	764	.33754	521	.28997	354	.24449	268	.20095	13
48	810	.33673	568	.28919	402	.24375	317	.20024	12
49	855	.33592	615	.28842	450	.24301	366	.19953	11
50	.74900	1.33511	.77661	1.28764	.80498	1.24227	.83415	1.19882	10
51	946	.33430	708	.28687	546	.24153	465	.19811	9
52	991	.33349	754	.28610	504	.24079	514	.19740	8
53	.75037	.33258	801	.28533	642	.24405	564	.19669	7
54	082	.33187	848	.28456	690	.23931	613	.19599	6
55	.75128	1,33107	.77895	1.28379	.80738	1.23858	.83662	1.19528	5
56	173	.33026	941	.28302	786	.23784	712	.19457	4
57	219	.32946	988	.28225	834	.23710	.761	.19387	3
58	264	.32865	.78035	.28148	882	.23637	811	.19316	2
59	310	.32785	082	.28071	930	.23563	860	.19246	1
60	.75355	1.32704	.78129	1.27994	.80978	1.23490	.83910	1.19175	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	53°		52°		51°		50°		

M.	40°		41°		42°		43°		
	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	
0	0.83910	1.19175	0.86929	1.15037	0.90040	1.11061	0.93252	1.07237	60
1	960	.19105	980	.14969	093	.10996	306	.07174	59
2	.84009	.19035	.87031	.14902	146	.10931	360	.07112	58
3	059	.18964	.082	.14834	199	.10867	415	.07049	57
4	108	.18894	133	.14767	251	.10802	469	.06987	56
5	.84158	1.18824	.87184	1.14699	.90304	1.10737	.93524	1.06925	55
6	208	.18754	236	.14632	357	.10672	578	.06862	54
7	258	.18684	287	.14565	410	.10607	633	.06800	53
8	307	.18614	338	.14498	463	.10543	688	.06738	52
9	357	.18544	389	.14430	516	.10478	742	.06676	51
10	.84407	1.18474	.87441	1.14363	.90569	1.10414	.93797	1.06613	50
11	457	.18404	492	.14296	621	.10349	852	.06551	49
12	507	.18334	543	.14229	674	.10285	906	.06489	48
13	556	.18264	595	.14162	727	.10220	961	.06427	47
14	606	.18194	646	.14095	781	.10156	.94016	.06365	46
15	.84656	1.18125	.87698	1.14028	.90834	1.10091	.94071	1.06303	45
16	706	.18055	749	.13961	887	.10027	125	.06241	44
17	756	.17986	801	.13894	940	.09963	180	.06179	43
18	806	.17916	852	.13828	993	.09899	235	.06117	42
19	856	.17846	904	.13761	.91046	.09834	290	.06056	41
20	.84906	1.17777	.87955	1.13694	.91099	1.09770	.94345	1.05994	40
21	956	.17708	.88007	.13627	153	.09706	400	.05932	39
22	.85006	.17638	059	.13561	206	.09642	455	.05870	38
23	057	.17569	110	.13494	259	.09578	510	.05809	37
24	107	.17500	162	.13428	313	.09514	565	.05747	36
25	.85157	1.17430	.88214	1.13361	.91366	1.09450	.94620	1.05685	25
26	207	.17361	265	.13295	419	.09386	676	.05624	34
27	257	.17292	317	.13228	473	.09322	731	.05562	33
28	308	.17223	369	.13162	526	.09258	786	.05501	32
29	358	.17154	421	.13096	580	.09195	841	.05439	31
30	.85408	1.17085	.88473	1.13029	.91633	1.09131	.94896	1.05378	30
31	458	.17016	524	.12963	687	.09067	952	.05317	29
32	509	.16947	576	.12897	.740	.09003	.95007	.05255	28
33	559	.16878	628	.12831	794	.08940	062	.05194	27
34	609	.16809	680	.12765	847	.08876	118	.05133	26
35	.85660	1.16741	.88732	1.12699	.91901	1.08813	.95173	1.05072	25
36	710	.16672	784	.12633	955	.08749	229	.05010	24
37	761	.16603	836	.12567	.92008	.08686	284	.04949	23
38	811	.16535	888	.12501	062	.08622	340	.04888	22
39	862	.16466	940	.12435	116	.08559	395	.04827	21
40	.85912	1.16398	.88992	1.12369	.92170	1.08496	.95451	1.04766	20
41	963	.16329	.89045	.12303	224	.08432	506	.04705	19
42	.86014	.16261	097	.12238	277	.08369	562	.04644	18
43	064	.16192	149	.12172	331	.08306	618	.04583	17
44	115	.16124	201	.12106	385	.08243	673	.04522	16
45	.86166	1.16056	.89253	1.12041	.92439	1.08179	.95729	1.04461	15
46	216	.15987	306	.11975	493	.08116	735	.04401	14
47	267	.15919	358	.11909	547	.08053	841	.04340	13
48	318	.15851	410	.11844	601	.07990	897	.04279	12
49	368	.15783	463	.11778	655	.07927	952	.04218	11
50	.86419	1.15715	.89515	1.11713	.92709	1.07864	.96008	1.04158	10
51	470	.15647	567	.11648	763	.07801	064	04097	9
52	521	.15579	620	.11582	817	.07738	120	04036	8
53	572	.15511	672	.11517	872	.07676	176	03976	7
54	623	.15443	725	.11452	926	.07613	232	03915	6
55	.86674	1.15375	.89777	1.11387	.92980	1.07550	.96288	1 03855	5
56	725	.15308	830	.11321	.93034	.07487	344	03794	4
57	776	.15240	883	.11256	088	.07425	400	.03734	3
58	827	.15172	935	.11191	143	.07362	457	.03674	2
59	878	.15104	988	.11126	197	.07299	513	.03613	1
60	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	0
	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	Cot.	Tan.	M.
	49°		48°		47°		46°		

APPENDIX IV.—Natural tangents and cotangents—Con.

M.	44°			M.	44°			M.	44°		
	Tan.	Cot.			Tan.	Cot.			Tan.	Cot.	
0	0.96569	1.03553	60	20	0.97700	1.02355	40	40	0.98843	1.01170	20
1	625	.03493	59	21	756	.02295	39	41	901	.01112	19
2	681	.03433	58	22	813	.02236	38	42	958	.01053	18
3	738	.03372	57	23	870	.02176	37	43	.99016	.00994	17
4	794	.03312	56	24	927	.02117	36	44	073	.00935	16
5	.96850	1.03252	55	25	.97984	1.02057	35	45	.99131	1.00876	15
6	907	.03192	54	26	.98041	.01998	34	46	189	.00818	14
7	963	.03132	53	27	098	.01939	33	47	247	.00759	13
8	.97020	.03072	52	28	155	.01879	32	48	304	.00701	12
9	076	.03012	51	29	213	.01820	31	49	362	.00642	11
10	.97133	1.02952	50	30	.98270	1.01761	30	50	.99420	1.00583	10
11	189	.02892	49	31	327	.01702	29	51	478	.00525	9
12	246	.02832	48	32	384	.01642	28	52	536	.00467	8
13	302	.02772	47	33	441	.01583	27	53	594	.00408	7
14	359	.02713	46	34	499	.01524	26	54	652	.00350	6
15	.97416	1.02653	45	35	.98556	1.01465	25	55	.99710	1.00291	5
16	472	.02593	44	36	613	.01406	24	56	768	.00233	4
17	529	.02533	43	37	671	.01347	23	57	826	.00175	3
18	586	.02474	42	38	728	.01288	22	58	884	.00116	2
19	643	.02414	41	39	786	.01229	21	59	942	.00058	1
20	.97700	1.02355	40	40	.98843	1.01170	20	60	1.00000	1.00000	0
	Cot.	Tan.	M.		Cot.	Tan.	M.		Cot.	Tan.	M.
	45°				45°				45°		

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